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LONG-TERM USE OF SEWAGE SLUDGE ON AGRICULTURAL AND DISTURBED LANDS

by

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Cooperative Agreement No. CR807780

Project Officer

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16. ABSTRACT

This report presents results from the last 2 years of a 15-year study of the long term use of sewage sludge on agricultural and distrubed lands. The three field studies discussed here include (1) the response of corn to repeated annual applications of sewage sludge, (2) the differential uptake of zinc (Zn) in two selected corn hybrids grown on sludge-amended soil, and (3) the effects of high sludge application rates on strip-mine spoil characteristics and the response of plants.

In the first study, anaerobically digested sludge was applied annually for 14 years by furrow irrigation to an acid Blount silt loam soil at average rates of 0, 12.5, 25, or 50 mt/ha (equivalent dry weight). Corn yields were higher during the last year than when the study was initiated for all treatment levels. Sludge applications caused reduced concentrations of Fe in corn stover, reduced Mn in leaf, grain, and stover, low but significant increases of Cu and Ni in all tissues, and marked increases of Cd and Zn in all tissues.

A corn hybrid selected to take up large amounts of Zn outyielded a low Zn accumulating hybrid, but the low Zn hybrid yields were increased more by sludge application.

A very stable digested dewaterd sludge applied to strip-mine spoil at rates of 0, 224, 448, and 896 mt/ha (dry weight) increased corn yield. The highest yields were from the highest sludge-use plots.

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FOREWORD

The U. S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies of the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution, and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and is a most vital communciations link between the researcher and the user community.

This report presents results of a study of long term use of wastewater sludge on land. Stabilized sludge was applied annually for 14 years on agricultural and strip mined lands at various rates and with various management schemes to achieve maximum benefits while minimizing environmental impacts and public health risks.

ABSTRACT

This report presents results from the last 2 years of a 15-year study of the long term use of sewage sludge on agricultural and disturbed lands. The three field studies discussed here include (1) the response of corn to repeated annual applications of sewage sludge, (2) the differential uptake of zinc (Zn) in two selected corn hybrids grown on sludge-amended soil, and (3) the effects of high sludge application rates on strip-mine spoil characteristics and the response of plants.

In the first study, anaerobically digested sludge was applied annually for 14 years by furrow irrigation to an acid Blount silt loam soil at average rates of 0, 12.5, 25, or 50 mt/ha (equivalent dry weight). No sludge was applied during the last year. Corn yields were higher during the last year than when the study was initiated for all treatment levels. Though organic-C, N, P, Zn, Cd, Cu, Ni, Cr, and Pb concentrations increased in the 0- to 30-cm depth of soil in proportion to sludge loading rates, they were not significantly increased by annual sludge applications during the last 7 years of the study. Sludge applications caused reduced concentrations of Fe in corn stover, reduced Mn in leaf, grain, and stover, low but significant increases of Cu and Ni in all tissues, and marked increases of Cd and Zn in all tissues. The chemical composition of corn tissues for all treatments was not significantly different than that observed 5 years before to the last year of the study.

A corn hybrid selected to take up small amounts of Zn was compared with one that took up large amounts of the element. Split plots were used to grow the two hybrids with and without annual sludge applications. The sludge applications increased the yields of the low-Zn hybrid, but not those of the high-Zn hybrid, the latter produced significantly higher yields at all treatment levels, and it produced stover with lower Cu concentrations than did the low-Zn accumulator.

Three years before the study ended, digested sludge was dredged from a storage lagoon, dewatered, and incorporated into the surface of level strip-mine spoil banks at rates of 0, 224, 448, and 896 mt/ha (dry weight). At the end of the 2-year period, organic-C and N contents had not changed. These results indicated that the sludge-borne organic matter was very stable and resistant to decomposition. Concentrations of sludge-borne P, Zn, Cd, Cr, Cu, Ni, and Pb had remained fairly stable in the 0- to 30-cm depth of spoil.

During the last year, corn yields were highest on plots treated with the highest sludge application rate. Concentrations of N, Zn, Mn, Ni, Cd, and Cu were increased in corn tissues by sludge treatments to about the same level observed in previous years. Chemical changes in wheat and rye tissues attributable to sludge applications were similar to those in corn tissues. Concentrations of N, P, Mg, Cd, Cu, Ni, and Zn generally increased in grass samples of eight different species growing on sludge-treated plots, compared with samples from control plots. But none of the chemical elements in grasses were present at levels that would present a health hazard to animals consuming them.

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SECTION I

INTRODUCTION

This report describes the results of three field studies conducted during the last 2 years of a 15-year investigation into the long-term use of sewage sludge on agricultural or disturbed land. The first study examines the response of corn to repeated annual applications of sewage sludge. The second study investigates the differential uptake of zinc (Zn) in two selected corn hybrids grown under field conditions on sludge-amended soil. And the third study documents changes in strip-mine spoil characteristics and the response of plants to high rates of sewage sludge applications.

The first study reports the results of the last 2 years of the 15-year study in which anaerobically digested sludge was applied annually, except for the last years, to an acid Blount silt loam by furrow irrigation while corn was growing on the ridges. Results from the first 13 years of production on these plots (identified as the NW 800 series of plots at the Northeastern Agronomy Research Center, Elwood, Illinois), have been reported and discussed in research progress reports (Hinesly and Hansen, 1979; Hinesly et al., 1982). The main objective of this study was to determine (1) the effects of sewage sludge on soil productivity, and (2) changes in the chemical composition of plants, especially regarding the accumulation of sludge-borne heavy metals in soils and plant parts.

Results are also reported here from the first year of a field study to test the differences in Zn uptake from sludge-amended Blount soil by single-crosses of corn produced from parents that took up either large or small amounts of the element. This study was conducted on the south series of Blount silt loam lysimeter plots located at the Northeast Agronomy Research Center. These plots were most recently used to conduct a similar study of differential Cd uptake by selected hybrids (Hinesly et al., 1982). The short-term objective of this study was to determine (1) the relationship between corn yields and Zn uptake by plants growing on sludge-amended soils, and (2) the effects of Zn uptake on the uptake of other metals supplied as sludge constituents. The long-term objectives of this study and the study involving Cd uptake were to determine the feasibility of producing excellent-yielding corn hybrids that would produce high-Zn grain and low-Cd grain, regardless of the amounts of these and other sludge-borne metals in soils.

Findings are also reported here from the last year of a 3-year study to measure crop plant responses to changes in the chemical and physical

properties of calcareous strip-mine spoil produced by digested sewage sludge applied at rates far exceeding those needed for maximum crop production. The field plots used for this study were located on lands owned by the Metropolitan Sanitary District of Chicago near Canton, Illinois. The main objective of this 3-year crop study was to determine maximum one-time loading rates for grasses and producing acceptable yields of grain by corn, wheat, and rye in management systems that would minimize erosion.

SECTION II

CONCLUSIONS

After 14 years of applying digested sludge on Blount silt loam soil (NW-800 series), no evidence suggested that a phytotoxic condition was imminent. Concentrations of Cd, Cu, Ni, and Zn were consistently enhanced in the leaf, grain, and stover of corn grown on sludge-amended plots, but little evidence showed that repeated annual applications of these sludge-borne metals had a significant effect on the accumulation of these metals in the above-ground parts of corn. The reason for this phenomenon is the fact that during the last several years, annual sludge applications failed to increase the levels of organic matter and heavy metals in the 0- to 15-cm depth of soil and only slightly increased metals in the 15- to 30-cm depth. Relative to the amounts of metals applied, those migrating to depths below 30 cm were negligible. Since erosion was also negligible on these nearly level plots, it appears that several sludge constituents, including transition and heavy metals, were lost by volatilization processes either before the sludge was incorporated into the soil or immediately thereafter.

Data from a single-season study indicated that a single-cross corn hybrid with an inherited capacity to take up large amounts of zinc produced higher grain yields and tended to accumulate less Cu in above-ground plant parts than the low-Zn accumulator when grown together on maximum sludge-treated plots. Verification in subsequent crop years is needed, however, to validate the effect.

As compared with sludges drawn directly from digesters, digested sludge dredged from storage lagoons contained lower organic-C concentrations and higher metal contents. After sludge was incorporated into calcareous strip-mine spoil, the initial increased organic-C and metal contents in the 0- to 15-cm depth of spoil never decreased during the 3-year study. Thus the organic matter remaining in this sludge was very resistant to microbial decomposition in strip-mine spoil. Corn grown on mine spoil amended with high rates of this dewatered, stable sludge had markedly less uptake of sludge-borne Cd and Zn than did the same corn hybrid grown on plots treated with less stable sludge that was incrementally applied over several years on similar spoil material. This difference occurred in spite of the fact that total concentrations of Cd and Zn were eight times higher in the spoil amended with the one-time, high-rate sludge application.

SECTION III

RECOMMENDATIONS

The following recommendations are based on the findings presented in this report:

1. Further work should be done to determine the pathways by which transition and heavy metals were lost when liquid digested sludge was repeatedly applied on soils for several years.

2. Further work should be done to determine whether or not the transition and heavy metals remaining in soils will continue to be lost after sludge applications are terminated.

3. Further work should be done to determine why transition and heavy metals incorporated in strip-mine spoil as constituents of a dewatered and very stable sludge (as judged by its organic-C contents) were not lost and were considerably less available for uptake by plants.

4. Further work should be done to select species and develop varieties of grain and forage plants that would insure minimal uptakes of sludge-borne Cd, and maintain the potential for high yields of crops with adequate concentrations of essential trace elements for animals in the plant parts used as feedstuffs.

SECTION IV

FIELD STUDIES

RESPONSE OF CONTINUOUS CORN ON BLOUNT SILT LOAM TO REPEATED ANNUAL APPLICATIONS OF SEWAGE SLUDGE

Introduction

This report contains the results obtained during the last 2 years of a 15-year study where anaerobically digested sludge was annually applied for 14 years by furrow irrigation on plots of Blount silt loam continuously planted to corn (*Zea mays* L.). Two reports prepared previously contain the results obtained from 1968 through 1980 (Hinesly et al. 1981, Hinesly et al. 1982).

Materials and Methods

Four replications of 6.1 by 12.1 m plots with four sludge treatments randomized within blocks were established in 1968 on Blount silt loam soil (Aeric ochraqualf, fine, illitic, mesic) occupying part of the cultivated area on the Northeast Agronomy Research center near Joliet, IL. Digested sludge was applied by furrow irrigation first in 1968 and annually thereafter during the growing season and sometimes during the fall after grain harvest. All plots were annually fertilized with a broadcast application of KCl to supply 134 kg K/ha, and control (zero liquid sludge) plots were further treated with annual broadcast fertilizer applications supplying 268 kg N/ha and 134 kg P/ha. As often as weather conditions permitted, liquid digested sludge was transported by truck-trailer tanks from MSD of Chicago Southwest or Calumet wastewater treatment plants and applied at liquid depths of 25.4 mm (maximum), 12.7 mm (one-half maximum), and 6.4 mm (one-fourth maximum) to each of the appropriate plots on the same day.

Immediately after ridges and furrows were established, corn was planted at rates calculated to give a plant population of 60,000 plants per hectare on top of ridges spaced 76 cm apart. In general, sludge was applied for the first time each year when corn plants had reached a height of about 15 cm.

After 1972, six soil cores to a depth of 76 cm were taken from each plot, using stainless steel tubes. Soil cores were segmented and composited to provide representative samples of the 0 to 15, 15 to 30, 30 to 46, and 61 to 76 cm soil depths. After drying (60°C), crushing, and pulverizing (60-mesh screen) soil samples (0.5 g) were heated to 500°C for 24 h, digested in concentrated HCl-HF, and dissolved in 1.0 N HCl for total heavy

metal analyses by atomic absorption spectrophotometry. As an estimate of availability for uptake of metals by plants, 1 g of soil from all sampled depths was extracted with 20 ml of 0.1 N HCl, through 1974. Soil pH was determined in one-to-one soil to water paste.

Sludge samples, collected at the beginning and end of each irrigation event, were prepared and analyzed in a manner similar to that for soil after they were dried (110°C) to a constant weight, except they were not digested with HCl-HF. Total organic carbon concentrations in soil and sludge samples were determined by the Walkley-Black procedure as described by Allison, et al., (1965). Total nitrogen concentrations were determined by the semimicro-Kjeldahl method as discussed by Bremner (1965). The ammonium saturation method, in accordance with Chapman's (1965) directions, was used to determine soil cation-exchange capacities.

Samples of corn leaves, opposite and below the primary ear shoots, were collected when about 10% of the plants had tasseled. Leaf samples were washed in distilled water immediately after cutting, dried at 60°C, and ground in a Wiley mill to pass a 20-mesh screen. Corn yields were determined by hand-harvesting the two center rows from each plot. Grain samples were collected from larger shelled-grain samples used to determine yield response. After stalk counts were made on plots, twenty-five growing plants were randomly selected and harvested from the two center rows and weighed. From the twenty-five plants, four were randomly selected for moisture determinations and analyses for chemical constituents. Both grain and chopped stover samples were dried and ground in the same manner as leaf samples. Leaf, grain, and stover subsamples (2 g) were wet ashed in concentrated HNO_3 at 90°C, followed by $HClO_4$ at 200°C, taken to dryness and dissolved in 1.0 N HNO_3 for determining metal concentrations by atomic absorption spectrophotometry. Total N and P concentrations in plants were determined respectively by micro-Kjeldahl (Horwitz, 1970) and modified vanadomolybdate (Jackson, 1958) procedures.

The study protocol remained unchanged during the 14 years, except, as explained in the last progress report, during the last two years the 8-row plots were split and planted to two corn hybrids. Because production of the original hybrid (Pioneer 3517), which was planted each year from the beginning of the study was discontinued, enough seed was purchased to continue planting it in four rows of the 8-row plots for an additional three years. The remaining four rows in each plot were planted with a new hybrid (Pioneer 3541) so that its response to sewage sludge could be compared with the old hybrid. This comparison appeared to be essential from the standpoint of determining long-term effects of annual sludge applications on the growth and uptake of nutrients and heavy metals by corn. Unfortunately, only two years of comparison data were obtained before this longest continuous study was terminated because of the lack of funds.

Results and Discussion

Sludge loading rates during 1981 amounted to 10.2 cm on maximum-treated plots and supplied 31.8 mt/ha of solids (dry weight) as reported in Table 1. Appropriately smaller amounts were applied on 1/4- and

TABLE 1. ANNUAL DIGESTED SLUDGE LOADING RATES AND TOTAL ACCUMULATIONS ON MAXIMUM-SLUDGE-TREATED BLOUNT SILT LOAM PLOTS PLANTED TO CORN

Year	Liquid Sludge Applied (cm)		Dry Solids Applied (mt/ha)	
	Annual	Accumulations	Annual	Accumulations
1968-1980	-	253.3	-	733.3
1981	10.2	263.5	31.8	765.1

1/2- maximum-treated plots. The 1981 sludge applications brought the total accumulated sludge applications during the 14-year study to 765 mt/ha on maximum-treated plots.

Concentrations of several sludge constituents are presented in Table 2, along with accumulative amounts of these constituents applied on maximum-treated plots during the 14-year period. Accumulative applications of sludge-borne metals such as Cd, Cu, Ni, and Zn were extremely high, relative to amounts that would have caused a phytoxic condition if they were applied as soluble salts. It may be seen in Table 3, that in 1981 about 70 percent of the sludge-borne N was in the form of NH_4-N. Thus, the proportion of total N in the form of NH_4-N was considerably higher than had been present in sludges applied in previous years.

Soil organic-C and total N levels were significantly increased by higher sludge-application rates in the 0 to 15 cm soil depth, but not in deeper soil profile depths (Table 4). Concentrations of K, Na, Ca, Mg, Fe, and Mn in soil were not significantly increased by sludge applications. But, P, Zn, Cd, Cu, Ni, Cr, and Pb concentrations were significantly increased in the 0 to 30 cm depths of soil by sludge applications. Soil samples below 30 cm were collected but were not analyzed because in past years there was little indication that concentrations of metals in soil below 30 cm had been affected by sludge applications. In 1981, differences in soil pH were not significant, but in former years higher sludge applications had generally resulted in small, significant decreases in soil pH.

Plant populations ranged from 54 to 62 thousand plants per hectare during the last year of the study and thus there was no indication that sludge applications had affected seed germination and seedling establishments (Table 5). Grain and stover yields from the two corn hybrids were not significantly increased by sludge applications as compared to yields from highly fertilized control plots. Yields from both hybrids in 1981 were markedly higher than averages of yields in previous years. Thus, after 14 years of repeated sludge applications there was no indication that corn was adversely affected by chemical constituents accumulating in the acid soil. On sludge fertilized plots there was a statistically insignificant trend for higher grain and lower stover yields with the new corn hybrid as compared to the one that had been used throughout the study period. Apparently, the new hybrid had a higher capacity to respond to higher fertility levels than did the old hybrid. As can be seen in Table 6, amounts of rainfall during the last year of the study were considerably above average and was ideally distributed during the growing season. Corn yields obtained during this study are among the highest ever recorded for Blount silt loam.

The data presented in Table 7 show that, in general, N contents of leaf, stover, and grain were not increased by sludge applications. Concentrations of P were increased only in corn leaves. Calcium and Mg contents of corn plant tissues were not altered by sludge applications. Iron contents in stover and Mn contents in plant tissues were decreased by sludge applications, but deficiency symptoms for these elements were never observed in corn. The ability to detect these decreases indicates that plant

TABLE 2. AVERAGE CONTENTS AND TOTAL ANNUAL AMOUNTS OF SEVERAL CONSTITUENTS OF SLUDGE APPLIED ON THE MAXIMUM-TREATED BLOUNT SILT LOAM PLOTS PLANTED TO CORN. APPROPRIATELY LESSER AMOUNTS OF SLUDGE FROM THE SAME BATCH WERE APPLIED ON OTHER SLUDGE-TREATED PLOTS ON THE SAME DAY

Year	Solids	P	K	Na	Ca	Mg	Fe	Mn	Cd	Cu	Cr	Ni	Pb	Zn
	--%--													
		Annual Means of Analytes in Sludge (mg/l wet weight)												
1981	3.14	890	232	104	1012	468	1500	6	5.7	48	72	15	22	94
		Amounts of Analytes Applied as Constituents of Sludge (kg/ha dry weight)												
1968-1981	-	23589	3997	-	25269	9725	33305	344	191	1067	2259	279	790	3748

TABLE 3. AVERAGE CONTENTS AND TOTAL AMOUNTS OF VARIOUS FORMS OF N AND ASH CONTENTS OF SOLIDS ANNUALLY APPLIED AS CONSTITUENTS OF SLUDGE ON BLOUNT SILT LOAM

Year	% Ash	Total N	NH_4-N	NO_3-N
	Annual Means of Analytes in Sludge (mg/kg wet weight)			
1981	54.4	1300	916	11.3
	Amounts of Analytes Applied as Constituents of Sludge (kg/ha dry weight)			
1981	-	1320	930	11
1968-1981	-	41543	19429	--

TABLE 4. CONCENTRATIONS OF TOTAL MACRO- AND TRACE-ELEMENTS, ORGANIC-C, AND pH DETERMINED FROM SOIL SAMPLES COLLECTED AT DEPTHS OF 0 TO 15 AND 15 TO 30 cm IN BLOUNT SILT LOAM PLOTS[a/b/c/]

Parameter	Depth cm	Year	Sludge Application Rates 0	1/4 Max	1/2 Max	Max	LSD
			%				
Organic C	0-15	1981	1.31	1.92	2.56	3.11	0.50**
	15-30	1981	0.80	0.75	0.90	1.23	n.s.
N	0-15	1981	0.096	0.154	0.204	0.225	0.061**
	15-30	1981	0.089	0.086	0.084	0.114	n.s.
P	0-15	1981	0.081	0.153	0.251	0.370	0.088**
	15-30	1981	0.061	0.066	0.094	0.136	0.048*
K	0-15	1981	1.94	1.90	1.88	1.86	n.s.
	15-30	1981	1.91	1.92	1.92	1.89	n.s.
Na	0-15	1981	0.810	0.825	0.812	0.814	n.s.
	15-30	1981	0.748	0.751	0.734	0.756	n.s.
Ca	0-15	1981	0.520	0.696	0.654	0.668	n.s.
	15-30	1981	0.473	0.497	0.458	0.495	n.s.
Mg	0-15	1981	0.417	0.455	0.403	0.398	n.s.
	15-30	1981	0.483	0.508	0.512	0.469	n.s.
Fe	0-15	1981	1.96	1.91	2.00	2.11	n.s.
	15-30	1981	2.24	2.34	2.51	2.32	n.s.
			mg/kg				
Mn	0-15	1981	850	990	986	995	n.s.
	15-30	1981	730	691	620	750	n.s.
Zn	0-15	1981	78	222	372	532	58**
	15-30	1981	79	113	155	224	73**
Cd	0-15	1981	0.6	8.4	16.1	24.7	3.4**
	15-30	1981	0.7	2.4	4.2	8.1	3.9**
Cu	0-15	1981	19	64	110	165	28**
	15-30	1981	22	31	43	64	20**
Ni	0-15	1981	23	32	41	53	8**
	15-30	1981	25	27	30	32	5**

(continued)

TABLE 4. (continued)

Parameter	Depth cm	Year	Sludge Application Rates 0	1/4 Max	1/2 Max	Max	LSD
			mg/kg				
Cr	0-15	1981	33	97	155	216	24**
	15-30	1981	36	49	62	87	27**
Pb	0-15	1981	24	58	92	127	11**
	15-30	1981	23	28	36	53	22**
			Units				
pH	0-15	1981	6.0	6.4	6.0	5.8	n.s.
	15-30	1981	5.3	5.3	4.8	5.0	n.s.

a/ Concentrations are on a dry weight basis
b/ Digested sludge was applied annually on replicated plots at various rates and control or check plots were annually treated with a relatively high rate of inorganic fertilizer.
c/ Samples were collected from plots identified as the NW 800 series.
*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.
n.s. = non-significant F-test.

TABLE 5. PLANT POPULATIONS AND CORN GRAIN AND STOVER YIELDS FROM PLOTS DESIGNATED NW 800

Year	Sludge Application Rates 0	1/4 Max	1/2 Max	Max	LSD
			Population		
			1,000 plants/ha		
			Pioneer 3517		
1981	55.5	55.2	55.2	55.0	
			Pioneer 3541		
1981	54.2	53.8	61.9	58.7	
			Grain Yields		
			mt/ha (15.5% moisture)		
			Pioneer 3517		
1981	9.80	9.85	9.43	9.07	n.s.
1968-1981 Ave.	6.33	6.92	7.27	7.61	n.s.
			Pioneer 3541		
1981	9.56	9.88	10.85	10.75	n.s.
1980-1981 Ave.	6.04	6.28	6.80	7.14	n.s.
			Stover Yields		
			mt/ha (dry weight)		
			Pioneer 3517		
1981	9.71	10.80	11.50	13.00	n.s.
			Pioneer 3541		
1981	8.18	8.34	10.60	12.00	n.s.

n.s. = no significant differences.
*, ** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

TABLE 6. AVERAGE RAINFALL AT THE NORTHEAST AGRONOMY RESEARCH CENTER DURING THE 1981 GROWING SEASON. THE 1941 TO 1970 AVERAGE RAINFALL FOR THE AREA IS PRESENTED FOR COMPARISON

	Month						
Year	April	May	June	July	August	September	Totals
	Rainfall in cm						
1981	16.0	11.1	19.5	20.2	15.2	5.3	87.3
1941-1970 Average	9.4	9.1	10.4	9.8	7.7	8.4	54.8

TABLE 7. AVERAGE CONTENTS OF MACROELEMENTS AND MINOR ELEMENTS IN CORN LEAF, STOVER, AND GRAIN TISSUE SAMPLES FROM BLOUNT SILT LOAM PLOTS

Constituent	Year	Sludge Treatment 0	1/4 Max	1/2 Max	Max	LSD
		%				
		Pioneer 3517 Leaf				
N	1981	2.99	2.56	3.14	2.87	n.s.
		Pioneer 3541 Leaf				
	1981	2.78	3.05	2.95	3.14	n.s.
		Pioneer 3517 Stover				
	1981	0.95	0.72	0.95	1.05	n.s.
		Pioneer 3541 Stover				
	1981	0.83	0.74	0.72	0.83	n.s.
		Pioneer 3517 Grain				
	1981	1.38	1.18	1.28	1.46	n.s.
		Pioneer 3541 Grain				
	1981	1.21	1.18	1.20	1.19	n.s.
		Pioneer 3517 Leaf				
P	1981	0.316	0.401	0.447	0.406	0.041**
		Pioneer 3541 Leaf				
	1981	0.278	0.346	0.401	0.378	0.037**
		Pioneer 3517 Stover				
	1981	0.188	0.137	0.170	0.296	0.095*
		Pioneer 3541 Stover				
	1981	0.132	0.119	0.109	0.176	n.s.
		Pioneer 3517 Grain				
	1981	0.349	0.356	0.367	0.380	n.s.
		Pioneer 3541 Grain				
	1981	0.299	0.309	0.299	0.319	n.s.

(continued)

TABLE 7. (continued)

Constituent	Year	Sludge Treatment 0	1/4 Max	1/2 Max	Max	LSD
				%		
				Pioneer 3517 Leaf		
Ca	1981	0.712	0.734	0.744	0.747	n.s.
				Pioneer 3541 Leaf		
	1981	0.712	0.705	0.750	0.792	0.053*
				Pioneer 3517 Stover		
	1981	0.546	0.456	0.485	0.634	n.s.
				Pioneer 3541 Stover		
	1981	0.468	0.411	0.447	0.498	n.s.
				mg/kg		
				Pioneer 3517 Grain		
	1981	22	25	19	34	n.s.
				Pioneer 3541 Grain		
	1981	29	34	34	32	n.s.
				%		
				Pioneer 3517 Leaf		
Mg	1981	0.257	0.284	0.276	0.264	n.s.
				Pioneer 3541 Leaf		
	1981	0.290	0.302	0.298	0.296	n.s.
				Pioneer 3517 Stover		
	1981	0.205	0.202	0.202	0.224	n.s.
				Pioneer 3541 Stover		
	1981	0.206	0.196	0.195	0.197	n.s.
				Pioneer 3517 Grain		
	1981	0.128	0.131	0.135	0.138	n.s.
				Pioneer 3541 Grain		
	1981	0.106	0.110	0.105	0.111	n.s.

(continued)

TABLE 7. (continued)

Constituent	Year	Sludge Treatment 0	1/4 Max	1/2 Max	Max	LSD
				%		
				Pioneer 3517 Leaf		
Fe	1981	159	162	144	140	n.s.
				Pioneer 3541 Leaf		
	1981	144	136	141	137	n.s.
				Pioneer 3517 Stover		
	1981	228	320	116	119	135*
				Pioneer 3541 Stover		
	1981	200	102	109	113	58*
				Pioneer 3517 Grain		
	1981	22	26	24	24	n.s.
				Pioneer 3541 Grain		
	1981	21	25	23	24	n.s.
				Pioneer 3517 Leaf		
Mn	1981	74	43	41	39	18**
				Pioneer 3541 Leaf		
	1981	74	47	46	43	17**
				Pioneer 3517 Stover		
	1981	60	36	30	32	19**
				Pioneer 3541 Stover		
	1981	49	31	28	31	8**
				Pioneer 3517 Grain		
	1981	6.1	4.2	3.5	3.5	1.2**
				Pioneer 3541 Grain		
	1981	4.8	4.0	3.2	3.3	0.6**

(continued)

TABLE 7. (continued)

Constituent	Year	Sludge Treatment 0	1/4 Max	1/2 Max	Max	LSD
		%				
		Pioneer 3517 Leaf				
Zn	1981	54	135	222	306	39**
		Pioneer 3541 Leaf				
	1981	41	109	189	289	36**
		Pioneer 3517 Stover				
	1981	33	132	255	344	47**
		Pioneer 3541 Stover				
	1981	23	118	212	299	45**
		Pioneer 3517 Grain				
	1981	25	39	48	53	12**
		Pioneer 3541 Grain				
	1981	24	36	41	46	6**
		Pioneer 3517 Leaf				
Cd	1981	0.4	4.8	13.4	20.7	3.0**
		Pioneer 3541 Leaf				
	1981	0.2	1.3	3.6	6.7	1.1**
		Pioneer 3517 Stover				
	1981	0.7	11.0	33.4	48.6	13.1**
		Pioneer 3541 Stover				
	1981	0.5	3.6	10.1	15.3	6.0**
		Pioneer 3517 Grain				
	1981	<0.06	0.41	0.81	1.06	0.32**
		Pioneer 3541 Grain				
	1981	<0.06	0.06	0.14	0.18	0.10**

(continued)

TABLE 7. (continued)

Constituent	Year	Sludge Treatment 0	1/4 Max	1/2 Max	Max	LSD
				%		
				Pioneer 3517 Leaf		
Cu	1981	8.6	11.4	11.9	13.4	1.1**
				Pioneer 3541 Leaf		
	1981	9.4	12.1	12.5	13.6	0.9**
				Pioneer 3517 Stover		
	1981	5.6	7.3	8.1	8.9	1.7**
				Pioneer 3541 Stover		
	1981	5.6	7.1	6.7	7.1	n.s.
				Pioneer 3517 Grain		
	1981	1.7	2.1	1.8	2.4	0.5*
				Pioneer 3541 Grain		
	1981	1.6	1.9	1.9	1.8	0.2*
				Pioneer 3517 Leaf		
Ni	1981	0.8	1.1	1.1	1.9	0.6**
				Pioneer 3541 Leaf		
	1981	<0.6	0.6	0.9	1.5	0.6**
				Pioneer 3517 Stover		
	1981	0.6	<0.6	1.1	2.3	1.4**
				Pioneer 3541 Stover		
	1981	1.3	1.6	1.9	1.2	n.s.
				Pioneer 3517 Grain		
	1981	<0.6	<0.6	0.9	1.9	0.8**
				Pioneer 3541 Grain		
	1981	<0.6	<0.6	0.7	1.6	0.3**

(continued)

TABLE 7. (continued)

Constituent	Year	Sludge Treatment 0	1/4 Max	1/2 Max	Max	LSD
				%		
				Pioneer 3517 Leaf		
Cr	1981	0.7	0.7	0.9	0.8	n.s.
				Pioneer 3541 Leaf		
	1981	0.6	0.5	0.6	0.5	n.s.
				Pioneer 3517 Stover		
	1981	<0.1	<0.1	<0.1	0.3	n.s.
				Pioneer 3541 Stover		
	1981	1.0	<0.1	0.6	<0.1	n.s.
				Pioneer 3517 Grain		
	1981	<0.12	0.18	<0.12	<0.12	n.s.
				Pioneer 3541 Grain		
	1981	<0.12	<0.12	<0.12	<0.12	n.s.
				Pioneer 3517 Leaf		
Pb	1981	2.5	2.6	2.4	2.1	n.s.
				Pioneer 3541 Leaf		
	1981	3.0	2.6	2.8	2.7	n.s.
				Pioneer 3517 Stover		
	1981	4.6	4.6	3.8	4.4	n.s.
				Pioneer 3541 Stover		
	1981	2.1	1.5	1.8	1.8	n.s.
				Pioneer 3517 Grain		
	1981	0.9	0.9	3.9	2.1	n.s.
				Pioneer 3541 Grain		
	1981	1.5	1.2	0.8	1.8	n.s.

n.s. = no significant differences.
*, ** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

tissues were not contaminated by sludge during its application by furrow irrigation. Both Zn and Cd concentrations were markedly increased in all plant tissues by sludge applications. However, the concentrations of Cd were significantly less in the tissues of the new hybrid as compared to those in similar tissues of the original hybrid. In grain from maximum-treated plots, Cd concentrations were 0.18 and 1.06 mg/kg for the new and old hybrids, respectively. At the lowest sludge treatment level, which is a loading rate recommended as an optimum rate based on amounts of N supplied, Cd concentrations in tissues from the new hybrid were at the upper range of values expected in similar tissues of corn grown on uncontaminated soils. Low, but statistically significant, increases of Cu and Ni were found in corn tissues produced on plots treated with the two higher sludge loading rates. Even though high amounts of sludge-borne Cr and Pb was applied each of the 14 years, during the last year of the study there was no indication that concentrations of these two elements had been enhanced in corn tissues.

DIFFERENTIAL ACCUMULATIONS OF ZN BY CORN HYBRIDS GROWN ON BLOUNT SILT LOAM AMENDED WITH SEWAGE SLUDGE

Introduction

The screening of 20 corn inbreds, commonly used as parents of hybrids adapted to the cornbelt region, showed a marked difference in their capacity to accumulate Cd and Zn from sewage sludge-amended soil (Hinesly, et al., 1978). Although the magnitude of Cd concentrations in corn leaf and grain tissues were much lower than those for Zn, the relative differences in Cd concentrations between inbreds was much higher than those of Zn. Results from further studies showed that the capacity of corn to take up Cd and Zn was under genetic control (Hinesly et al., 1982). Single-cross hybrids selected to take up either low or high amounts of Cd were planted each of three years on split-plots of sludge-amended Blount silt loam in a field study. A consistent significant difference in Cd uptake between the two selected hybrids was found. Similar to the Cd study, the objective of this study was to demonstrate the constancy of differential uptakes of Zn between two selected corn hybrids grown under field conditions on sludge-treated soil.

Materials and Methods

Single-crosses H99 X W64A and A619 X A632 were selected as low and high Zn accumulators, respectively, and planted in split-plots of Blount silt loam, which had received annual sludge applications by furrow irrigation for the 12 years before initiation of the Zn study. Three replications for each of the three different sludge loading rates and a control (no sludge) were randomized within the study area. Liquid digested sludge from the Southwest Wastewater Treatment plant in Chicago, Illinois, containing 1.5 to 3.5% suspended solids, was applied each year by furrow irrigation at approximate plot depths of 6.4, 12.7, and 25.4 mm. At each sludge application, control plots were irrigated with 25.4 mm of water. Successive applications were made when sufficient sludge moisture had been lost by infiltration and evaporation to permit additional sludge to be added to the maximum-sludge-treated (25.4 mm) plots. Thus, the frequency of sludge applications varied as a result of differences in climatic conditions during the growing season. All plots were fertilized with a broadcast application of KCl to supply 112 K/ha prior to plowing, ridging, and planting operations. Control plots also received 336 kg N/ha as NH_4NO_3 and 112 kg P/ha as triple superphosphate.

Seeds of either the H99 x W64A or A619 x A632 hybrid were hand-planted on ridges of randomly selected halves of plots at rates to provide populations of 60,000 plants/ha after thinning. When about 15% of the plants tasseled, the leaf adjacent to the ear node was collected from 10 plants in

each split-plot, washed in distilled water, dried at 60°C, and ground to pass a 20-mesh screen. Subsamples of grain, hand-harvested from split-plots to determine yields, were dried and ground in the same manner as leaf samples. After grain harvest, 12 and 13 consecutive plants from the two center rows were harvested and weighed for a determination of stover yields. From the 25 plants, four plants were randomly selected, chopped into short segments with a corn knife, dried at 60°C to determine moisture contents, and ground to pass a 20-mesh screen. Leaf, grain and stover samples (2g) were digested in concentrated HNO_3 at 90°C, followed by $HClO_4$ at 200°C taken to dryness, dissolved in 0.1 N HNO_3 and analyzed for Ca, Mg, K, Fe, Mn, Cd, Cu, Cr, Ni, Pb, and Zn concentrations by atomic absorption spectrophotometry with appropriate background correction. Phosphorus concentrations were determined colorimetrically with the vanadomolybdate finish (Greweling, 1976) and N by a method described by Bremner (1965).

Soil samples were collected with stainless steel tubes to a depth of 76 cm from each plot following the first spring tillage operation and segmented into depths of 15 cm. After drying (60°C), crushing, and pulverizing to pass a 60-mesh screen, aliquots (0.5 g) were heated to 500°C for 24 hours, digested in concentrated HCl-HF, and dissovled in 1 N HCl for determining metal concentrations by atomic absorption spectrophotometry.

When the Zn study was initiated in 1981, maximum-treated Blount silt loam plots had received an accumulative sludge loading rate equivalent to 648 mt/ha of dry sewage solids (Table 8). During 1981, an additional 12.7 cm of sludge was applied on maximum-treated plots, which supplied 36.5 mt/ha of solids. Appropriately lesser amounts of sludge were applied on 1/4- and 1/2-maximum-treated plots, at the same time as the maximum applications. Accumulative amounts of several sludge-borne constituents applied on maximum sludge-treated soils are presented in Table 9. It is noteworthy that at the beginning of the Zn study more than 2,900 kg/ha of sludge-borne Zn had been applied on maximum-treated plots and 105 kg Zn/ha was applied during the study year. Accumulative applications of sludge had supplied 38,452 kg/ha of N, of which about 47 percent was in the NH_4-N form (Table 10).

Results and Discussion

Concentrations of various chemical elements in plots of the Blount soil used for the Zn study are presented in Table 11. Concentrations of organic-C, Total N, P, Zn, Cd, Cu, Ni, Cr, and Pb had been increased in the 0 to 15 cm depth of soil by increasingly higher applications of sludge, but not by repeated annual applications of sludge. There was a trend for Zn, Cd, Cu, Ni, Cr, and Pb concentrations to be increased in the 15 to 30 cm depth of soil with increasingly higher applications of sludge, but these were not markedly high concentrations nor always statistically significant. There was very little evidence that metal concentrations were increased by sludge applications at soil depths below 30 cm. No explanation can be given for the disappearance of sludge-borne heavy metals at rates equivalent to their additions each year. Maximum sludge application rates reduced soil pH by about 0.5 units, but did not appear to be a progressive decrease with repeated annual applications of sludge.

TABLE 8. ANNUAL DIGESTED SLUDGE LOADING RATES AND TOTAL ACCUMULATIONS ON MAXIMUM-SLUDGE-TREATED BLOUNT SILT LOAM LYSIMETER PLOTS, SOUTH SERIES

Year	Liquid Sludge Applied (cm)		Dry Solids Applied (mt/ha)	
	Annual	Accumulations	Annual	Accumulations
1969-1980	-	236.9	-	648.2
1981	12.7	248.6	36.5	684.7

TABLE 9. AVERAGE CONTENTS AND TOTAL ANNUAL AMOUNTS OF SEVERAL CONSTITUENTS OF SLUDGE APPLIED ON THE MAXIMUM-TREATED BLOUNT SILT LOAM LYSIMETER PLOTS, SOUTH SERIES. APPROPRIATELY LESSER AMOUNTS OF SLUDGE FROM THE SAME BATCH WERE APPLIED ON OTHER SLUDGE-TREATED PLOTS ON THE SAME DAY

Year	Solids	P	K	Na	Ca	Mg	Fe	Mn	Cd	Cu	Cr	Ni	Pb	Zn
	--%--													
		Annual Means of Analytes in Sludge (mg/l wet weight)												
1981	3.11	910	278	132	975	454	1259	6	6.1	49	72	15	21	105
		Amounts of Analytes Applied as Constituents of Sludge (kg/ha dry weight)												
1969-1981	-	20966	-	-	22040	8265	28821	316	178	889	1956	248	715	3015

TABLE 10. AVERAGE CONTENTS AND TOTAL AMOUNTS OF VARIOUS FORMS OF N AND ASH CONTENTS OF SOLIDS ANNUALLY APPLIED AS CONSTITUENTS OF SLUDGE ON BLOUNT SILT LOAM LYSIMETER PLOTS, SOUTH SERIES

Year	% Ash	Total N	NH_4-N	NO_3-N
	Annual Means of Analytes in Sludge (mg/kg wet weight)			
1981	52.1	1730	862	11.8
	Amounts of Analytes Applied as Constituents of Sludge (kg/ha dry weight)			
1981	-	2039	1016	14
1969-1981	-	38452	18120	-

TABLE 11. CONCENTRATIONS OF TOTAL MACRO-AND TRACE-ELEMENTS, ORGANIC-C, AND pH DETERMINED FROM SOIL SAMPLES COLLECTED AT DEPTHS OF 0 TO 15, 15 TO 30, 30 TO 46, AND 61 TO 76 cm IN BLOUNT SILT LOAM LYSIMETER PLOTS[a/b/c/]

Parameter	Depth cm	Year	Sludge Treatment 0	1/4 Max	1/2 Max	Max	LSD
			%				
Organic C	0-15	1978	1.11	1.60	2.33	3.03	0.46**
		1979	1.04	1.44	2.16	2.95	0.52**
		1980	1.40	1.68	2.18	2.93	0.68**
		1981	1.26	1.33	2.15	2.54	0.56**
	15-30	1978	0.72	0.87	1.07	0.86	n.s.
		1979	0.69	0.74	0.92	0.88	n.s.
		1980	0.76	0.55	0.77	0.82	n.s.
		1981	0.57	0.64	0.76	0.63	n.s.
	30-46	1978	0.49	0.53	0.62	0.52	n.s.
		1979	0.37	0.47	0.50	0.49	n.s.
	61-76	1978	0.43	0.55	0.48	0.49	n.s.
		1979	0.41	0.46	0.46	0.45	n.s.
N	0-15	1978	0.122	0.150	0.214	0.283	0.041**
		1979	0.110	0.140	0.197	0.257	0.047**
		1980	0.114	0.150	0.180	0.262	0.047**
		1981	0.106	0.130	0.184	0.220	0.022**
	15-30	1978	0.079	0.106	0.100	0.155	n.s.
		1979	0.077	0.083	0.080	0.093	n.s.
		1980	0.084	0.080	0.087	0.090	n.s.
		1981	0.066	0.080	0.083	0.071	n.s.
	30-46	1978	0.065	0.074	0.076	0.077	n.s.
		1979	0.067	0.070	0.070	0.070	n.s.
	61-76	1978	0.060	0.063	0.062	0.063	n.s.
		1979	0.060	0.060	0.067	0.063	n.s.

(continued)

TABLE 11. (continued)

Parameter	Depth cm	Year	Sludge Treatment 0	1/4 Max	1/2 Max	Max	LSD
			%				
P	0-15	1978	0.085	0.133	0.185	0.260	0.098**
		1979	0.080	0.127	0.240	0.353	0.070**
		1980	0.083	0.138	0.194	0.324	0.065**
		1981	0.078	0.110	0.224	0.323	0.090**
	15-30	1978	0.031	0.033	0.048	0.036	n.s.
		1979	0.035	0.041	0.040	0.050	n.s.
		1980	0.033	0.041	0.042	0.033	n.s.
		1981	0.040	0.049	0.041	0.044	n.s.
	30-46	1978	0.032	0.036	0.032	0.034	n.s.
		1979	0.032	0.031	0.037	0.033	n.s.
	61-76	1978	0.029	0.031	0.027	0.030	n.s.
		1979	0.036	0.035	0.038	0.038	n.s.
K	0-15	1978	2.20	2.21	2.13	2.14	n.s.
		1979	2.19	2.25	2.22	2.20	n.s.
		1980	2.11	2.16	2.06	2.09	n.s.
		1981	2.13	2.15	2.09	2.18	n.s.
	15-30	1978	1.79	1.97	1.86	1.87	n.s.
		1979	2.16	2.26	2.16	2.23	n.s.
		1980	2.26	2.30	2.11	2.22	n.s.
		1981	1.98	2.16	2.03	2.18	0.16**
	30-46	1978	2.03	2.34	2.02	2.23	n.s.
		1979	1.74	2.08	2.26	2.03	n.s.
	61-76	1978	3.00	2.81	2.97	3.18	n.s.
		1979	2.68	2.50	2.44	2.22	n.s.

(continued)

TABLE 11. (continued)

Parameter	Depth cm	Year	Sludge Treatment 0	1/4 Max	1/2 Max	Max	LSD
			----------	----------	%----------	----------	
Na	0-15	1978	0.673	0.637	0.652	0.633	n.s.
		1979	0.639	0.642	0.634	0.612	n.s.
		1980	0.672	0.668	0.681	0.643	n.s.
		1981	0.758	0.688	0.704	0.703	n.s.
	15-30	1978	0.528	0.514	0.580	0.582	n.s.
		1979	0.693	0.611	0.689	0.620	0.073**
		1980	0.755	0.639	0.733	0.654	0.078**
		1981	0.748	0.653	0.697	0.666	n.s.
	30-46	1978	0.616	0.517	0.582	0.498	n.s.
		1979	0.576	0.530	0.573	0.560	n.s.
	61-76	1978	0.653	0.544	0.584	0.597	n.s.
		1979	0.553	0.489	0.505	0.461	n.s.
Ca	0-15	1978	1.57	1.63	1.48	1.47	n.s.
		1979	1.22	1.28	1.17	1.14	n.s.
		1980	1.14	1.14	1.01	1.12	n.s.
		1981	1.23	1.49	1.27	1.21	n.s.
	15-30	1978	0.89	0.84	0.68	0.60	n.s.
		1979	0.50	0.58	0.48	0.67	n.s.
		1980	0.62	0.76	0.52	0.59	n.s.
		1981	0.65	0.82	0.49	0.51	n.s.
	30-46	1978	0.80	0.53	0.54	0.39	n.s.
		1979	0.41	0.41	0.49	0.67	n.s.
	61-76	1978	0.83	1.53	1.02	1.67	n.s.
		1979	0.84	0.95	0.44	1.46	n.s.

(continued)

TABLE 11. (continued)

Parameter	Depth cm	Year	Sludge Treatment 0	1/4 Max	1/2 Max	Max	LSD
					%		
Mg	0-15	1978	0.954	0.987	0.893	0.883	n.s.
		1979	0.854	0.907	0.871	0.820	n.s.
		1980	0.904	0.905	0.813	0.856	n.s.
		1981	0.825	0.854	0.834	0.843	n.s.
	15-30	1978	0.592	0.629	0.516	0.535	n.s.
		1979	0.550	0.670	0.494	0.656	n.s.
		1980	0.634	0.745	0.575	0.668	n.s.
		1981	0.591	0.728	0.529	0.654	n.s.
	30-46	1978	0.901	0.877	0.744	0.734	n.s.
		1979	0.763	0.941	0.795	0.972	n.s.
	61-76	1978	1.04	1.44	1.24	1.47	n.s.
		1979	0.974	1.06	0.691	1.03	n.s.
Fe	0-15	1978	2.52	2.58	2.62	2.77	n.s.
		1979	2.43	2.23	2.62	2.42	n.s.
		1980	2.86	2.86	2.60	2.97	n.s.
		1981	2.63	2.76	2.76	2.88	n.s.
	15-30	1978	2.85	2.94	2.67	2.72	n.s.
		1979	2.34	2.73	2.28	2.57	n.s.
		1980	2.21	2.81	2.36	2.54	n.s.
		1981	2.61	3.27	2.97	3.33	n.s.
	30-46	1978	3.47	3.81	3.26	4.04	n.s.
		1979	3.94	4.43	3.78	4.24	n.s.
	61-76	1978	4.63	3.93	4.04	4.08	n.s.
		1979	4.90	4.53	4.67	4.39	n.s.

(continued)

TABLE 11. (continued)

Parameter	Depth cm	Year	Sludge Treatment 0	1/4 Max	1/2 Max	Max	LSD
			%				
Mn	0-15	1978	888	880	835	797	n.s.
		1979	923	861	829	763	n.s.
		1980	945	901	909	788	n.s.
		1981	992	900	911	852	n.s.
	15-30	1978	1170	1020	1350	1150	n.s.
		1979	803	732	866	834	n.s.
		1980	749	742	776	813	n.s.
		1981	757	767	844	789	n.s.
	30-46	1978	487	496	498	435	n.s.
		1979	408	475	505	468	n.s.
	61-76	1978	561	634	529	698	n.s.
		1979	705	673	654	616	n.s.
Zn	0-15	1978	77	216	385	602	125**
		1979	73	200	390	606	94**
		1980	79	268	321	537	127**
		1981	73	187	338	507	115**
	15-30	1978	68	80	94	70	15*
		1979	58	71	65	86	14*
		1980	79	82	77	84	n.s.
		1981	70	92	83	94	n.s.
	30-46	1978	84	95	88	103	12*
		1979	80	92	91	82	n.s.
	61-76	1978	102	107	107	121	n.s.
		1979	108	97	111	97	n.s.

(continued)

TABLE 11. (continued)

Parameter	Depth cm	Year	Sludge Treatment 0	1/4 Max	1/2 Max	Max	LSD
			%				
Cd	0-15	1978	0.47	7.77	17.7	28.3	6.29**
		1979	0.44	7.17	17.6	30.1	5.66**
		1980	0.72	8.97	14.3	26.3	4.87**
		1981	0.37	6.89	15.5	24.7	5.70**
	15-30	1978	<0.25	<0.25	1.38	0.50	0.80**
		1979	<0.25	0.47	0.47	1.46	0.75**
		1980	<0.25	0.53	0.67	0.61	n.s.
		1981	0.33	0.95	0.49	1.15	n.s.
	30-46	1978	<0.25	<0.25	<0.25	<0.25	n.s.
		1979	<0.25	<0.25	<0.25	<0.25	n.s.
	61-76	1978	<0.25	<0.25	<0.25	<0.25	n.s.
		1979	0.41	<0.25	<0.25	0.25	n.s.
Cu	0-15	1978	27	49	102	161	36**
		1979	22	64	124	191	37**
		1980	24	77	111	201	35**
		1981	22	60	114	166	31**
	15-30	1978	33	30	37	38	n.s.
		1979	21	26	22	31	6*
		1980	20	27	23	26	n.s.
		1981	22	31	22	29	5*
	30-46	1978	27	34	26	41	9*
		1979	29	30	29	29	n.s.
	61-76	1978	29	35	28	31	n.s.
		1979	36	32	36	33	n.s.

(continued)

TABLE 11. (continued)

Parameter	Depth cm	Year	Sludge Treatment 0	1/4 Max	1/2 Max	Max	LSD
					%		
Ni	0-15	1978	27	36	53	68	19**
		1979	23	35	48	66	12**
		1980	24	38	42	63	8**
		1981	29	40	53	67	13**
	15-30	1978	32	26	28	25	n.s.
		1979	19	25	20	26	4**
		1980	23	29	23	27	n.s.
		1981	26	33	27	33	5*
	30-46	1978	28	36	21	31	9*
		1979	28	32	25	32	n.s.
	61-76	1978	44	63	43	56	n.s.
		1979	45	48	50	42	n.s.
Cr	0-15	1978	52	135	273	395	76**
		1979	43	114	206	309	54**
		1980	45	108	143	241	44**
		1981	44	99	156	222	56**
	15-30	1978	48	52	60	51	n.s.
		1979	41	48	40	52	7**
		1980	37	43	37	42	n.s.
		1981	36	46	36	42	6*
	30-46	1978	58	68	62	73	n.s.
		1979	42	51	50	49	n.s.
	61-76	1978	73	78	78	76	n.s.
		1979	60	60	62	62	n.s.

(continued)

TABLE 11. (continued)

Parameter	Depth cm	Year	Sludge Treatment 0	1/4 Max	1/2 Max	Max	LSD
			----------	----------	%[a] ----------	----------	
Pb	0-15	1978	20	45	74	118	31**
		1979	25	45	90	134	30**
		1980	26	58	77	154	69**
		1981	26	49	82	117	26**
	15-30	1978	20	22	28	25	n.s.
		1979	19	21	21	26	n.s.
		1980	18	21	22	21	n.s.
		1981	18	25	22	23	4*
	30-46	1978	17	20	19	20	n.s.
		1979	18	18	18	19	n.s.
	61-76	1978	29	30	27	33	n.s.
		1979	21	18	20	19	n.s.
			----------	----------	Units ----------	----------	
pH	0-15	1978	7.3	7.6	7.1	6.9	0.4*
		1979	7.4	7.6	7.3	7.0	0.3*
		1980	7.3	7.4	7.1	6.8	0.4*
		1981	7.6	7.4	7.2	6.8	0.5**
	15-30	1978	6.8	6.5	6.2	6.3	n.s.
		1979	7.0	6.7	6.5	7.0	n.s.
		1980	7.1	6.5	6.3	6.9	n.s.
		1981	7.1	6.8	6.5	6.4	n.s.
	30-46	1978	6.0	5.4	5.1	4.6	n.s.
		1979	6.1	5.3	5.3	5.8	n.s.
	61-76	1978	6.2	6.8	5.7	6.8	n.s.
		1979	7.0	7.2	6.4	7.2	n.s.

a/ Concentrations are on a dry weight basis.
b/ Digested sludge was applied annually on replicated plots at various rates and control or check plots were annually treated with a relatively high rate of inorganic fertilizer.
c/ Samples were collected from plots identified as the SIH series.
*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.
n.s. = non-significant F-test.

The data for corn grain and stover yields exhibited in Table 12 show that sludge applications increased grain yields of only the hybrid selected for its potential capacity to take up low amounts of Zn. The hybrid selected for its capacity to take up high amounts of Zn produced higher grain yields than did the low-Zn accumulator. Differences in stover yields were not significant between the two hybrids.

In general, concentrations of N, P, Ca, Mg, Fe, Ni, Cr, and Pb in corn tissues were not affected by sludge applications (Table 13). Concentrations of Zn, Cd, and Cu were increased in leaf and stover tissues from both hybrids by sludge application, but, as noted from the NW 800 series data, concentrations of Mn were generally decreased in all corn tissues including the grain. Zinc concentrations differed in the two hybrids only in leaf tissues collected from plots treated with maximum amounts of sludge. At all treatment levels, Cu concentrations were higher in stover produce by the hybrid selected to take up low amounts of Zn as contrasted to stover from the hybrid produce from parents that took up high amounts of Zn.

TABLE 12. GRAIN (ADJUSTED TO 15.5% MOISTURE) AND STOVER (DRY WT.) YIELDS PRODUCED BY TWO CORN HYBRIDS ON SPLIT-PLOTS OF BLOUNT SILT LOAM WITH AND WITHOUT SEWAGE SLUDGE

	H99 x W 64A (Low Zn)					A619 x A632 (High Zn)				
	Sludge Irrigation Rates (mm)									
Year	0	6.4	12.7	25.4	LSD	0	6.4	12.7	25.4	LSD
	mt/ha									
	Grain									
1981	6.76	8.25	8.80	8.79	1.02**	8.86	9.26	9.56	9.57	n.s.
	Stover									
1981	5.63	5.66	5.96	5.70	n.s.	6.38	5.63	5.34	5.20	n.s.

** Significantly different at $P \leq 0.01$.
n.s. = not significantly different.

TABLE 13. CONCENTRATIONS (DRY WEIGHT) OF MACRO- AND MINOR-ELEMENTS IN LEAVES, GRAIN AND STOVER OF TWO CORN HYBRIDS GROWN ON SPLIT-PLOTS OF BLOUNT SILT LOAM, WITH AND WITHOUT SEWAGE SLUDGE

	H99 x W64A (Low Zn) Sludge Irrigation Rates (mm)					A619 x A632 (High Zn) Sludge Irrigation Rates (mm)				
Tissue	0	6.4	12.7	25.4	LSD	0	6.4	12.7	25.4	LSD
	%					%				
Nitrogen										
leaf	2.59	2.59	2.83	2.60	n.s.	2.71	2.56	2.44	2.60	n.s.
grain	1.35	1.10	1.49	1.40	n.s.	1.34	1.29	1.30	1.34	n.s.
stover	0.62	0.58	0.67	0.71	n.s.	0.60	0.56	0.61	0.60	n.s.
Phosphorous										
leaf	0.311	0.272	0.287	0.303	0.025*	0.295	0.246	0.258	0.289	0.036**
grain	0.323	0.264	0.290	0.330	n.s.	0.308	0.278	0.275	0.312	n.s.
stover	0.116	0.066	0.067	0.099	n.s.	0.065	0.042	0.047	0.052	n.s.
Calcium										
leaf	0.525	0.589	0.559	0.524	0.039**	0.554	0.542	0.559	0.498	n.s.
grain	0.002	0.003	0.003	0.002	n.s.	0.003	0.004	0.004	0.004	n.s.
stover	0.418	0.436	0.434	0.416	n.s.	0.342	0.367	0.348	0.314	n.s.
Magnesium										
leaf	0.247	0.277	0.282	0.250	n.s.	0.314	0.288	0.286	0.277	n.s.
grain	0.124	0.106	0.113	0.129	n.s.	0.130	0.129	0.124	0.128	n.s.
stover	0.215	0.243	0.251	0.212	0.025**	0.195	0.234	0.227	0.195	n.s.

(continued)

TABLE 13. (continued)

	H99 x W64A (Low Zn) Sludge Irrigation Rates (mm)					A619 x A632 (High Zn) Sludge Irrigation Rates (mm)				
Tissue	0	6.4	12.7	25.4	LSD	0	6.4	12.7	25.4	LSD
	mg/kg									
					Iron					
leaf	113	109	106	103	n.s.	112	106	108	97	n.s.
grain	21	18	21	23	n.s.	13	16	15	13	n.s.
stover	84	98	107	105	n.s.	76	106	71	68	n.s.
					Manganese					
leaf	40	30	28	27	8**	36	26	24	24	8*
grain	4.2	2.9	2.1	1.9	1.3*	4.6	3.7	3.2	2.2	0.9**
stover	34	24	24	21	n.s.	32	26	25	20	9**
					Zinc					
leaf	21	38	67	102	15**	21	46	63	120	15**
grain	16	20	22	28	n.s.	16	25	26	33	8**
stover	13	45	70	143	38**	7	51	70	174	76**
					Cadmium					
leaf	0.3	1.2	2.9	6.3	1.5**	0.3	1.9	2.8	5.7	1.0**
grain	0.12	<0.06	0.14	0.32	0.08**	<0.06	<0.06	<0.06	0.20	n.s.
stover	0.9	4.1	7.6	16.9	4.2**	0.6	3.6	7.8	16.7	6.6**

(continued)

TABLE 13. (continued)

	H99 x W64A (Low Zn) Sludge Irrigation Rates (mm)					A619 x A632 (High Zn) Sludge Irrigation Rates (mm)				
Tissue	0	6.4	12.7	25.4	LSD	0	6.4	12.7	25.4	LSD
	mg/kg									
Copper										
leaf	10.9	11.4	12.2	13.4	1.4**	10.4	10.6	10.9	12.5	1.2*
grain	2.1	2.6	2.6	2.8	n.s.	1.3	2.6	1.5	1.4	n.s.
stover	6.6	8.1	9.5	9.6	2.2**	4.3	5.8	6.4	5.4	1.0*
Nickel										
leaf	<0.6	0.9	0.7	1.2	n.s.	<0.6	<0.6	0.7	<0.6	n.s.
grain	<0.6	<0.6	<0.6	<0.6	n.s.	<0.6	<0.6	<0.6	<0.6	n.s.
stover	<0.6	0.7	1.0	1.2	0.6*	0.9	1.0	0.7	0.7	n.s.
Chromium										
leaf	0.3	<0.1	<0.1	<0.1	0.1*	0.4	0.4	1.0	0.6	n.s.
grain	<0.1	<0.1	<0.1	<0.1	n.s.	<0.1	<0.1	<0.1	<0.1	n.s.
stover	<0.1	0.3	1.1	0.8	n.s.	<0.1	0.3	0.2	0.1	n.s.
Lead										
leaf	1.4	1.2	1.0	1.2	n.s.	0.7	0.7	0.6	0.4	n.s.
grain	1.9	1.2	2.0	2.9	n.s.	0.5	1.4	0.8	2.7	n.s.
stover	2.2	2.0	3.0	2.0	n.s.	2.1	2.1	2.7	2.2	n.s.

** Significantly different at $P<0.01$.
* Significantly different at $P<0.05$.
n.s. = not significantly different.

CHANGES IN STRIP-MINE SPOIL CHARACTERISTICS AND RESPONSE OF PLANTS TO HIGH-RATE SEWAGE SLUDGE APPLICATIONS

Introduction

Results obtained from the first two of a three-year study, where digested sewage sludge was dredged from a storage basin, dewatered and applied on calcareous strip-mine spoil at rates of 0, 224, 448, or 896 mt/ha, were previously reported by Hinesly et al. (1982). The objective of this study was to identify species of plants and cropping systems that would provide and maintain maximum vegetative cover toward minimizing erosion processes on and sediment losses from sludge-amended spoil areas.

Methods and Materials

An experimental site, with good surface drainage, was selected on spoil banks which had been in place for about 30 years. The spoil material had a silty clay loam texture, $CaCO_3$ equivalent of 3.2%, and pH value of 7.5. Replicated (three) plots, having the dimensions of 21 x 18 m, were treated with 0 (control), 224, 448, and 896 mt/ha (dry weight equivalent) of digested sewage sludge that had an average moisture content of 45%. Control plots received 123 kg/ha of N, P_2O_5, and K_2O each year prior to seeding wheat and rye. Following the application of sludge and its incorporation with a rotary plow, each main plot was subdivided into 9 plots of 3 x 6 m and two additional plots of 6 x 18.2 m. Each of the smaller subplots were seeded with one of the following grasses: big bluestem (Andropogon gerandi), orchard grass (Dactylis glomerate), perennial ryegrass (Lolium perenne), redtop (Agrostis alba), reed canarygrass (Phalaris arundinacea), smooth brome (Bromus inermis), tall fescue (Festuca elatior), timothy (Phleum pratense), and western wheatgrass (Agropyron smithii). Rye (Secal cereale) or wheat (Triticum vulgare) was seeded on the two larger subplots. During the first week of May, 3 m wide strips of rye and wheat were killed with paraquat and corn (Zea mays) was planted in the dead residues with a no-till planter.

From strips (3 x 18.2 m) of wheat and rye that were not sprayed with paraquat the top four leaves from 150 randomly selected plants were collected just before head emergence. Grain and straw samples were collected at the time of harvest. The leaf adjacent to the primary ear shoots was collected from ten corn plants in each of the dead wheat and rye plots when about 10% of the plants had tasseled. The leaves were washed with distilled water, dried at 60°C and ground in a Wiley mill. Corn grain and stalk samples were collected at the time of harvest.

Samples of spoil were collected from all main plots before sludge applications were made and each spring from subplots after sludge was

applied. Six 2.5 cm diameter samples were collected from each subplot with stainless steel tubes to a depth of 91 cm and composited by 15 cm depth increments, except the lower increment was 30 cm. Additional samples of the surface 15 cm depth were collected periodically for determination of organic carbon, nitrogen, conductivity of saturated extracts, and changes in physical properties.

Sludge and sludge-amended spoil samples were analyzed for C, N, P, K, Mg, Ca, Na, Fe, Mn, Zn, Cu, Cr, Pb, Ni, and Cd concentrations. Plant tissues were analyzed for contents of the same elements except C, K, Na. Chemical analyses were previously described by Hinesly et al., (1977) and the procedures for measuring physical properties were those described in Agronomy Monograph No. 9 (Black et al., 1965).

Results and Discussion

The organic-C and total N supplied by the sludge used in this study was somewhat less than one-half that of anaerobically digested sludge drawn directly from digesters. The data in Table 14 shows that for a particular sludge loading rate sludge-borne organic-C and N declined very little with time in 0 to 15 cm depth of spoil. Evidently the organic matter in this sludge was extremely stable against microbial decomposition. Along with organic-C and N, total concentrations of P, Ca, Mg, Fe, Zn, Cd, Cr, Cu, Ni, and Pb were significantly increased in the spoil in proportion to the sludge loading rates. Concentrations of K and Na were decreased in spoil by sludge additions, while concentrations of Mn remained unchanged. Concentrations of all elements remained rather constant in spoil surface samples collected, periodically, during a 31-month period. Concentrations of the various chemical elements in incremental depths of spoil, ranging from 0 to 91 cm are presented in Table 15. These data show that organic-C, N, P, Zn, Cd, Cr, Cu, Ni, and Pb added as constituents of sludge remained in the 0 to 30 cm depth of spoil. Changes in K, Na, Ca, Mg, and Fe concentrations resulting from sludge applications were restricted to the 0 to 15 cm depth of spoil. There was little indication that spoil material below a depth of 30 cm had been affected by sludge applications, except its pH had been lowered by the maximum sludge application to a depth of 30 to 46 cm. However, the magnitude of the pH change was very small, except in the 0 to 15 cm depth, where it was changed about one pH unit with the highest sludge application rate.

In years previous to the last year, corn grain yields were highest on plots treated with either 224 or 448 mt/ha of sludge. But during the third and last year of the study, the highest corn grain yields were obtained with the maximum sludge application rate (Table 16). As in past years, reliable estimates of wheat and rye grain yields were not obtained because of the foraging of geese on the young plants and birds on the seeds of these small grain crops. Sludge applications did not affect the concentrations of Mg, Ca, P, Fe, Cr, and Pb in corn tissue samples (Table 17). But in general sludge applications increased concentrations of N, Zn, Mn, Ni, Cd, and Cu in corn plant tissues. For those elements affected by sludge applications, concentrations in corn plant tissues were about at the same level during the last year of the study as they were in the first year.

TABLE 14. CONCENTRATIONS OF SELECTED CHEMICAL ELEMENTS IN SLUDGE AND THE 0-15 CM DEPTH OF SLUDGE-AMENDED SPOIL BANK MATERIAL. BEGINNING IN OCTOBER OF 1979, SEPARATE SPOIL SAMPLES WERE TAKEN FROM PLOTS PLANTED TO GRASSES (GR) AND CORN (CO)

Element	Sampling date	Sludge	Spoil (0-15 cm) Sludge Application Rates (mt/ha) 0	224	448	896	LSD
			% (dry weight)				
Org.-C	7-78	12.20	1.38	2.45	4.17	5.89	1.10**
	10-78		1.40	2.84	4.89	7.51	1.09**
	4-79		1.11	2.63	4.33	5.69	1.23**
	10-79 (Gr)		1.50	2.83	5.34	8.20	1.17**
	10-79 (Co)		1.49	3.28	4.72	6.94	1.94**
	3-80 (Gr)		1.16	2.41	3.56	5.64	2.04**
	3-80 (Co)		1.12	1.98	3.04	5.87	1.01**
	7-80 (Gr)		1.59	2.41	3.26	4.81	1.47**
	7-80 (Co)		1.58	2.32	2.83	4.81	1.48**
	10-80 (Gr)		1.16	2.26	3.19	6.11	1.35**
	10-80 (Co)		1.23	2.10	4.00	6.76	1.57**
	2-81 (Gr)		1.28	2.45	3.88	5.91	1.08**
	2-81 (Co)		1.18	2.15	3.80	5.97	0.75**
N	7-78	1.17	0.127	0.202	0.303	0.590	0.064**
	10-78		0.125	0.224	0.446	0.609	0.096**
	4-79		0.102	0.236	0.401	0.554	0.088**
	10-79 (Gr)		0.125	0.258	0.416	0.612	0.161**
	10-79 (Co)		0.131	0.264	0.392	0.575	0.151**
	3-80 (Gr)		0.103	0.199	0.326	0.536	0.216**
	3-80 (Co)		0.093	0.147	0.289	0.550	0.093**
	7-80 (Gr)		0.120	0.175	0.305	0.482	0.118**
	7-80 (Co)		0.094	0.172	0.258	0.427	0.108**
	10-80 (Gr)		0.103	0.199	0.287	0.473	0.157**
	10-80 (Co)		0.104	0.172	0.335	0.416	0.208**
	2-81 (Gr)		0.114	0.194	0.330	0.441	0.237**
	2-81 (Co)		0.103	0.174	0.315	0.533	0.072**

(continued)

TABLE 14. (continued)

Element	Sampling date	Sludge	Spoil (0-15 cm) Sludge Application Rates (mt/ha) 0	224	448	896	LSD
			% (dry weight)				
P	7-78	3.60	0.044	0.529	1.08	2.85	0.546**
	10-78		0.083	0.797	1.99	2.82	0.700**
	4-79		0.080	0.779	1.90	3.51	0.876**
	10-79 (Gr)		0.080	0.982	1.86	3.66	0.790**
	10-79 (Co)		0.079	0.840	1.66	3.28	0.819**
	3-80 (Gr)		0.075	0.703	1.30	2.72	1.34**
	3-80 (Co)		0.067	0.470	1.12	2.77	0.602**
	7-80 (Gr)		0.087	0.501	1.24	2.19	0.523**
	7-80 (Co)		0.072	0.415	0.996	2.07	0.438**
	10-80 (Gr)		0.076	0.564	1.14	3.33	1.01**
	10-80 (Co)		0.086	0.544	1.49	3.35	0.518**
	2-81 (Gr)		0.082	0.748	1.57	3.03	0.866**
	2-81 (Co)		0.088	0.560	1.54	3.38	0.384**
K	7-78	0.25	2.23	2.21	1.95	1.53	0.28**
	10-78		2.35	2.19	1.84	1.48	0.36**
	4-79		2.35	2.00	1.81	1.34	0.24**
	10-79 (Gr)		2.32	2.13	1.80	1.39	0.26**
	10-79 (Co)		2.39	2.20	1.94	1.44	0.17**
	3-80 (Gr)		1.80	1.61	1.73	1.47	n.s.
	3-80 (Co)		1.77	1.74	1.77	1.47	0.24**
	7-80 (Gr)		2.20	1.91	1.93	1.64	0.25**
	7-80 (Co)		2.31	2.01	1.96	1.60	0.34*
	10-80 (Gr)		2.36	2.24	2.07	1.59	0.34**
	10-80 (Co)		2.28	2.25	1.92	1.53	0.23**
	2-81 (Gr)		2.07	2.05	1.80	1.47	0.42**
	2-81 (Co)		2.19	2.06	1.83	1.43	0.29**

(continued)

TABLE 14. (continued)

Element	Sampling date	Sludge	Spoil (0-15 cm) Sludge Application Rates (mt/ha) 0	224	448	896	LSD
			% (dry weight)				
Na	7-78	0.04	0.997	1.12	0.884	0.874	n.s.
	10-78		0.853	0.741	0.703	0.557	0.124**
	4-79		0.970	0.874	0.725	0.550	0.137**
	10-79 (Gr)		0.895	0.805	0.650	0.537	0.144**
	10-79 (Co)		0.897	0.800	0.737	0.546	0.152**
	3-80 (Gr)		0.681	0.528	0.560	0.586	n.s.
	3-80 (Co)		0.639	0.590	0.607	0.544	n.s.
	7-80 (Gr)		0.900	0.563	0.750	0.629	0.185**
	7-80 (Co)		0.898	0.754	0.705	0.612	0.189*
	10-80 (Gr)		0.992	0.984	0.877	0.714	0.200**
	10-80 (Co)		0.963	0.976	0.820	0.685	0.214*
	2-81 (Gr)		0.903	0.829	0.730	0.667	0.166**
	2-81 (Co)		0.884	0.863	0.729	0.591	0.160**
Ca	7-78	4.04	0.683	1.07	1.55	2.25	0.685**
	10-78		0.604	0.880	1.70	2.29	0.422**
	4-79		0.612	1.09	1.69	2.32	0.523**
	10-79 (Gr)		0.582	0.967	1.43	2.50	0.575**
	10-79 (Co)		0.628	1.02	1.51	2.25	0.719**
	3-80 (Gr)		0.847	1.01	1.32	2.14	0.811**
	3-80 (Co)		0.759	0.863	1.40	2.02	0.932**
	7-80 (Gr)		0.600	0.549	1.16	1.60	0.350**
	7-80 (Co)		0.692	1.08	1.20	1.64	0.439*
	10-80 (Gr)		0.607	0.927	1.39	2.25	0.726**
	10-80 (Co)		0.712	0.938	1.40	2.37	0.354**
	2-81 (Gr)		0.555	0.890	1.24	1.84	0.597**
	2-81 (Co)		0.591	0.853	1.20	2.27	0.284**

(continued)

TABLE 14. (continued)

Element	Sampling date	Sludge	Spoil (0-15 cm) Sludge Application Rates (mt/ha) 0	224	448	896	LSD
			% (dry weight)				
Mg	7-78	1.70	0.795	1.02	1.05	1.40	0.371**
	10-78		0.802	0.809	1.10	1.24	0.249*
	4-79		0.980	1.02	1.13	1.29	0.168**
	10-79 (Gr)		0.919	1.02	1.03	1.30	0.151**
	10-79 (Co)		0.954	1.02	1.14	1.28	0.233**
	3-80 (Gr)		0.995	1.02	1.01	1.28	0.201**
	3-80 (Co)		1.04	0.997	1.07	1.26	0.169**
	7-80 (Gr)		0.949	0.537	1.00	1.08	0.166**
	7-80 (Co)		0.991	0.862	0.926	0.988	n.s.
	10-80 (Gr)		0.875	0.997	1.05	1.19	n.s.
	10-80 (Co)		0.891	1.05	1.01	1.27	n.s.
	2-81 (Gr)		0.759	0.903	0.856	1.08	0.187*
	2-81 (Co)		0.780	0.886	0.829	1.17	0.258*
Fe	7-78	6.85	4.48	4.94	6.00	8.08	2.22**
	10-78		3.76	4.68	6.44	8.37	0.84**
	4-79		3.76	4.48	6.32	8.26	1.75**
	10-79 (Gr)		3.76	4.94	6.17	9.10	1.50**
	10-79 (Co)		3.93	4.94	5.82	8.48	2.07**
	3-80 (Gr)		3.61	4.46	5.66	7.84	2.09**
	3-80 (Co)		3.75	4.36	5.30	7.81	1.18**
	7-80 (Gr)		4.07	4.57	5.48	7.03	1.16**
	7-80 (Co)		3.87	4.49	5.12	6.56	0.74**
	10-80 (Gr)		3.59	4.26	5.21	7.77	1.60**
	10-80 (Co)		4.06	4.54	5.68	7.97	1.42**
	2-81 (Gr)		4.16	4.82	6.16	8.25	1.50**
	2-81 (Co)		4.09	4.48	5.84	8.73	1.21**

(continued)

TABLE 14. (continued)

Element	Sampling date	Sludge	Spoil (0-15 cm) Sludge Application Rates (mt/ha) 0	224	448	896	LSD
			mg/kg (dry weight)				
Mn	7-78	817	630	636	621	722	n.s.
	10-78		629	600	662	677	n.s.
	4-79		548	654	652	625	n.s.
	10-79 (Gr)		598	602	619	648	n.s.
	10-79 (Co)		581	585	615	618	n.s.
	3-80 (Gr)		403	301	353	356	37.8**
	3-80 (Co)		435	398	445	366	n.s.
	7-80 (Gr)		556	565	592	639	n.s.
	7-80 (Co)		539	615	598	601	n.s.
	10-80 (Gr)		552	562	684	612	94.2*
	10-80 (Co)		603	541	561	612	n.s.
	2-81 (Gr)		327	366	381	340	n.s.
	2-81 (Co)		395	374	393	295	52.0*
Zn	7-78	4230	99.3	503	884	1660	603**
	10-78		87.6	627	1470	2550	321**
	4-79		84.8	729	1530	2500	750**
	10-79 (Gr)		94.9	991	1460	2770	595**
	10-79 (Co)		90.2	750	1350	2510	594**
	3-80 (Gr)		94.1	611	1380	2270	954**
	3-80 (Co)		94.2	475	993	2300	429**
	7-80 (Gr)		133	392	1040	1690	431**
	7-80 (Co)		91.9	440	905	1570	382**
	10-80 (Gr)		88.8	541	987	1930	703**
	10-80 (Co)		83.1	534	1190	2110	661**
	2-81 (Gr)		83.1	675	1310	2300	654**
	2-81 (Co)		74.3	546	1310	2420	295**

(continued)

TABLE 14. (continued)

Element	Sampling date	Sludge	Spoil (0-15 cm) Sludge Application Rates (mt/ha) 0	224	448	896	LSD
			mg/kg (dry weight)				
Cd	7-78	276	0.545	28.6	59.3	140	50.3**
	10-78		0.307	36.4	98.5	157	19.4**
	4-79		0.715	42.5	95.4	161	36.5**
	10-79 (Gr)		0.793	48.4	96.5	171	39.1**
	10-79 (Co)		0.469	45.9	84.8	163	34.7**
	3-80 (Gr)		0.943	31.2	70.4	136	63.5**
	3-80 (Co)		0.484	22.2	56.4	142	25.0**
	7-80 (Gr)		2.29	23.6	59.1	110	34.0**
	7-80 (Co)		0.435	22.5	56.0	99.0	25.3**
	10-80 (Gr)		1.09	29.1	60.0	139	42.3**
	10-80 (Co)		0.932	29.1	76.8	141	16.3**
	2-81 (Gr)		0.349	36.5	75.3	140	41.0**
	2-81 (Co)		<0.250	29.8	74.6	151	15.1**
Cr	7-78	2760	41.9	206	430	1130	408**
	10-78		47.6	215	566	994	152**
	4-79		43.6	390	847	1420	356**
	10-79 (Gr)		63.6	396	848	1550	487**
	10-79 (Co)		50.0	385	713	1240	363**
	3-80 (Gr)		53.8	310	625	1230	551**
	3-80 (Co)		52.4	235	529	1280	261**
	7-80 (Gr)		54.5	168	449	785	259**
	7-80 (Co)		47.9	177	360	720	204**
	10-80 (Gr)		48.1	231	492	1060	321**
	10-80 (Co)		50.0	244	640	1110	141**
	2-81 (Gr)		46.4	253	553	1040	389**
	2-81 (Co)		46.9	220	544	1080	136**

(continued)

TABLE 14. (continued)

Element	Sampling date	Sludge	Spoil (0-15 cm) Sludge Application Rates (mt/ha) 0	224	448	896	LSD
		mg/kg (dry weight)					
Cu	7-78	1380	36.6	174	345	684	158**
	10-78		29.9	192	463	746	101**
	4-79		26.5	213	431	693	158**
	10-79 (Gr)		32.9	244	478	828	174**
	10-79 (Co)		34.1	250	424	766	152**
	3-80 (Gr)		32.6	190	348	661	273**
	3-80 (Co)		32.4	144	299	680	109**
	7-80 (Gr)		35.0	144	333	544	135**
	7-80 (Co)		30.1	139	290	521	115**
	10-80 (Gr)		26.4	179	342	754	220**
	10-80 (Co)		28.4	149	326	574	57.1**
	2-81 (Gr)		29.8	224	420	770	227**
	2-81 (Co)		38.1	176	428	835	91.0**
Ni	7-78	284	35.8	62.6	99.5	176	54.1**
	10-78		39.9	79.4	129	201	22.8**
	4-79		44.4	88.8	138	203	37.6**
	10-79 (Gr)		30.4	64.6	114	172	31.3**
	10-79 (Co)		34.5	72.0	100	173	30.3**
	3-80 (Gr)		40.4	70.7	112	194	64.6**
	3-80 (Co)		38.3	69.4	105	196	24.8**
	7-80 (Gr)		45.7	61.9	103	153	36.4**
	7-80 (Co)		43.8	65.7	93.2	141	19.7**
	10-80 (Gr)		48.9	74.6	111	157	32.8**
	10-80 (Co)		49.7	76.4	102	155	27.0**
	2-81 (Gr)		61.1	99.9	139	210	47.1**
	2-81 (Co)		64.3	94.1	140	225	25.2**

(continued)

TABLE 14. (continued)

Element	Sampling date	Sludge	Spoil (0-15 cm) Sludge Application Rates (mt/ha) 0	224	448	896	LSD
			mg/kg (dry weight)				
Pb	7-78	1090	13.0	122	247	548	178**
	10-78		13.5	145	357	676	232**
	4-79		15.0	134	284	476	145**
	10-79 (Gr)		18.1	172	374	641	127**
	10-79 (Co)		18.8	178	318	604	111**
	3-80 (Gr)		18.7	140	269	540	251**
	3-80 (Co)		16.0	100	226	538	104**
	7-80 (Gr)		23.5	105	245	389	121**
	7-80 (Co)		12.5	103	212	389	111**
	10-80 (Gr)		14.3	135	243	547	168**
	10-80 (Co)		15.8	125	292	547	45.6**
	2-81 (Gr)		12.6	157	293	572	153**
	2-81 (Co)		13.3	126	293	567	187**

n.s. = not significant.
*, ** significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

TABLE 15. CONCENTRATIONS OF SELECTED CHEMICAL ELEMENTS IN SLUDGE-AMENDED SPOIL BANK MATERIALS IN 0 TO 15, 15 TO 30, 30 TO 46, 46 TO 61, AND 61 TO 91 CM DEPTHS[a/b/]

Analyte	Depths cm	Plot Type	Sludge Application Rates (mt/ha) 0	224	448	896	LSD
			(% dry weight)				
Org.-C	0-15	Corn	0.850	1.93	2.95	6.04	2.19**
		Grass	1.30	2.41	3.51	6.15	1.07**
	15-30	Corn	0.905	1.05	1.16	1.79	0.53**
		Grass	0.625	0.717	0.812	2.05	0.28**
	30-46	Corn	0.780	0.508	0.876	0.949	n.s.
		Grass	0.472	0.570	0.605	0.697	n.s.
	46-61	Corn	0.530	0.588	0.604	0.552	n.s.
		Grass	0.433	0.460	0.499	0.466	n.s.
	61-91	Corn	0.532	0.576	0.567	0.556	n.s.
		Grass	0.493	0.551	0.550	0.598	n.s.
N	0-15	Corn	0.094	0.184	0.276	0.480	0.134**
		Grass	0.102	0.218	0.305	0.554	0.086**
	15-30	Corn	0.053	0.063	0.079	0.126	0.035**
		Grass	0.056	0.066	0.069	0.168	0.015**
	30-46	Corn	0.054	0.052	0.057	0.054	n.s.
		Grass	0.051	0.056	0.053	0.065	n.s.
	46-61	Corn	0.051	0.052	0.053	0.054	n.s.
		Grass	0.048	0.049	0.051	0.056	n.s.
	61-91	Corn	0.052	0.054	0.046	0.053	n.s.
		Grass	0.048	0.053	0.052	0.057	n.s.

(continued)

TABLE 15. (continued)

Analyte	Depths cm	Plot Type	Sludge Application Rates (mt/ha) 0	224	448	896	LSD
			% (dry weight)				
P	0-15	Corn	0.084	0.631	1.38	3.23	0.935**
		Grass	0.083	0.823	1.62	3.81	0.779**
	15-30	Corn	0.067	0.081	0.134	0.303	0.143**
		Grass	0.058	0.095	0.113	0.474	0.081**
	30-46	Corn	0.064	0.059	0.071	0.071	n.s.
		Grass	0.058	0.062	0.077	0.071	n.s.
	46-61	Corn	0.074	0.058	0.067	0.063	n.s.
		Grass	0.060	0.062	0.069	0.064	n.s.
	61-91	Corn	0.057	0.058	0.068	0.064	n.s.
		Grass	0.075	0.056	0.065	0.064	n.s.
K	0-15	Corn	2.15	2.26	1.98	1.53	0.405**
		Grass	2.36	2.18	1.98	1.47	0.268**
	15-30	Corn	2.42	2.49	2.39	2.16	n.s.
		Grass	2.22	2.16	2.18	2.08	n.s.
	30-46	Corn	2.19	2.06	2.15	2.18	n.s.
		Grass	1.71	1.82	1.71	1.83	n.s.
	46-61	Corn	1.78	1.58	1.75	1.86	n.s.
		Grass	2.36	2.19	2.38	2.37	n.s.
	61-91	Corn	2.14	2.04	1.92	2.10	n.s.
		Grass	1.96	1.95	2.12	1.97	n.s.

(continued)

TABLE 15. (continued)

Analyte	Depths cm	Plot Type	Sludge Application Rates (mt/ha) 0	224	448	896	LSD
			% (dry weight)				
Na	0-15	Corn	1.00	1.09	0.999	0.689	0.201**
		Grass	1.05	1.01	0.912	0.623	0.206**
	15-30	Corn	1.19	1.11	1.16	1.10	n.s.
		Grass	0.916	0.916	0.879	0.870	n.s.
	30-46	Corn	0.916	0.862	0.896	0.909	n.s.
		Grass	0.726	0.730	0.642	0.776	n.s.
	46-61	Corn	0.743	0.665	0.734	0.825	n.s.
		Grass	1.16	1.19	1.09	1.12	n.s.
	61-91	Corn	0.928	0.902	0.815	0.885	n.s.
		Grass	0.764	0.760	0.866	0.772	n.s.
Ca	0-15	Corn	0.889	1.12	1.38	2.27	0.718**
		Grass	0.693	1.06	1.55	2.49	0.446**
	15-30	Corn	0.683	1.26	1.08	0.815	n.s.
		Grass	0.537	0.507	0.551	0.755	n.s.
	30-46	Corn	0.523	0.657	0.971	0.551	n.s.
		Grass	0.486	0.542	0.570	0.462	n.s.
	46-61	Corn	0.670	0.430	0.537	0.604	n.s.
		Grass	0.720	0.862	0.896	0.738	n.s.
	61-91	Corn	0.596	0.644	0.505	0.568	n.s.
		Grass	0.541	0.549	0.656	0.548	n.s.

(continued)

TABLE 15. (continued)

Analyte	Depths cm	Plot Type	Sludge Application Rates mt/ha 0	224	448	896	LSD
			% (dry weight)				
Mg	0-15	Corn	1.04	1.11	1.19	1.32	n.s.
		Grass	1.05	1.18	1.20	1.42	0.149**
	15-30	Corn	1.11	1.18	1.15	1.08	n.s.
		Grass	0.747	0.723	0.771	0.783	n.s.
	30-46	Corn	0.752	0.786	0.765	0.819	n.s.
		Grass	0.670	0.747	0.561	0.826	n.s.
	46-61	Corn	0.748	0.611	0.773	0.803	n.s.
		Grass	1.16	1.22	1.15	1.17	n.s.
	61-91	Corn	0.896	0.838	0.662	0.834	n.s.
		Grass	0.692	0.676	0.757	0.708	n.s.
Fe	0-15	Corn	3.97	4.49	5.56	8.04	2.16**
		Grass	4.08	4.81	6.19	9.19	1.25**
	15-30	Corn	3.90	4.10	4.19	4.17	n.s.
		Grass	3.97	4.18	4.15	4.70	n.s.
	30-46	Corn	4.04	3.74	4.03	4.01	n.s.
		Grass	4.13	3.88	4.19	3.82	n.s.
	46-61	Corn	4.03	3.64	4.17	3.92	n.s.
		Grass	3.78	4.22	4.04	4.08	n.s.
	61-91	Corn	3.73	3.88	3.64	4.09	n.s.
		Grass	4.11	3.77	4.23	4.13	n.s.

(continued)

TABLE 15. (continued)

Analyte	Depths cm	Plot Type	Sludge Application Rates (mt/ha) 0	224	448	896	LSD
			mg/kg (dry weight)				
Mn	0-15	Corn	599	552	684	531	n.s.
		Grass	569	540	1120	458	n.s.
	15-30	Corn	473	610	567	537	n.s.
		Grass	512	563	584	490	n.s.
	30-46	Corn	494	550	632	541	[illegible]
		Grass	451	468	532	386	[illegible]
	46-61	Corn	566	441	549	496	n.s.
		Grass	556	775	654	594	n.s.
	61-91	Corn	563	570	540	608	n.s.
		Grass	566	555	615	585	n.s.
Zn	0-15	Corn	78.0	610	1130	2420	784**
		Grass	78.0	730	1330	2810	482**
	15-30	Corn	91.3	105	156	321	102**
		Grass	84.4	114	141	596	138**
	30-46	Corn	76.4	62.2	76.8	77.8	n.s.
		Grass	85.6	91.8	93.1	106	n.s.
	46-61	Corn	83.8	79.4	82.7	84.4	n.s.
		Grass	90.5	79.9	117	95.1	n.s.
	61-91	Corn	88.7	81.5	83.5	82.5	n.s.
		Grass	88.2	86.2	88.7	87.2	n.s.

(continued)

TABLE 15. (continued)

Analyte	Depths cm	Plot Type	Sludge Application Rates mt/ha 0	224	448	896	LSD
			mg/kg (dry weight)				
Cd	0-15	Corn	<0.250	37.0	72.9	148	64.8**
		Grass	0.747	50.0	89.1	187	45.0**
	15-30	Corn	<0.250	0.717	3.80	14.5	9.78**
		Grass	<0.250	1.83	2.73	30.0	8.14**
	30-46	Corn	<0.250	<0.250	<0.250	<0.250	n.s.
		Grass	<0.250	<0.250	<0.250	0.427	n.s.
	46-61	Corn	<0.250	<0.250	<0.250	<0.250	n.s.
		Grass	<0.250	<0.250	<0.250	<0.250	n.s.
	61-91	Corn	<0.250	<0.250	<0.250	<0.250	n.s.
		Grass	<0.250	<0.250	<0.250	<0.250	n.s.
Cr	0-15	Corn	65.7	311	585	1200	518**
		Grass	64.1	383	689	1410	220**
	15-30	Corn	61.0	71.8	95.5	169	66.2**
		Grass	61.7	74.7	81.1	296	53.8**
	30-46	Corn	59.6	52.4	63.2	58.9	n.s.
		Grass	53.1	58.1	60.3	64.6	7.4*
	46-61	Corn	55.6	53.0	58.1	55.6	n.s.
		Grass	59.8	58.9	62.3	62.3	n.s.
	61-91	Corn	57.2	58.9	53.9	61.4	n.s.
		Grass	59.8	58.1	63.1	56.4	n.s.

(continued)

TABLE 15. (continued)

Analyte	Depths cm	Plot Type	Sludge Application Rates (mt/ha) 0	224	448	896	LSD
			mg/ha (dry weight)				
Cu	0-15	Corn	32.5	202	380	758	243**
		Grass	37.4	243	427	868	154**
	15-30	Corn	27.6	32.7	49.5	100	44.2**
		Grass	28.2	38.4	42.0	179	34.1**
	30-46	Corn	28.1	25.6	28.0	29.9	n.s.
		Grass	25.9	26.7	27.2	30.5	n.s.
	46-61	Corn	32.7	27.9	27.4	30.1	n.s.
		Grass	27.2	26.8	27.5	30.6	n.s.
	61-91	Corn	28.1	27.7	26.0	30.0	n.s.
		Grass	31.8	28.5	28.3	28.8	n.s.
Ni	0-15	Corn	53.3	84.3	115	190	43.6**
		Grass	57.2	75.2	124	207	58.1**
	15-30	Corn	53.5	55.5	60.4	65.8	5.3**
		Grass	54.2	54.3	55.0	85.1	12.9**
	30-46	Corn	54.0	49.2	54.5	52.7	n.s.
		Grass	48.1	52.4	51.5	53.2	n.s.
	46-61	Corn	49.9	50.9	47.3	52.7	n.s.
		Grass	52.0	49.5	53.9	50.9	n.s.

(Continued)

TABLE 15. (continued)

Analyte	Depths cm	Plot Type	Sludge Application Rates mt/ha 0	224	448	896	LSD
			mg/kg (dry weight)				
Pb	0-15	Corn	17.8	166	309	649	233**
		Grass	21.6	202	349	737	126**
	15-30	Corn	14.7	21.2	38.6	74.5	40.8**
		Grass	22.6	27.2	29.9	152	28.7**
	30-46	Corn	16.6	16.6	19.2	17.5	n.s.
		Grass	19.9	15.5	18.1	26.0	6.6*
	46-61	Corn	23.2	20.5	23.2	25.0	n.s.
		Grass	18.9	18.9	18.9	19.8	n.s.
	61-91	Corn	20.4	18.6	16.8	20.4	n.s.
		Grass	23.9	18.6	21.3	21.3	n.s.
			pH units				
pH	0-15	Corn	7.42	6.96	6.86	6.31	0.55**
		Grass	7.69	7.25	6.90	6.40	0.37**
	15-30	Corn	7.55	7.72	7.50	7.32	n.s.
		Grass	7.81	7.65	7.79	7.29	0.28*
	30-46	Corn	7.66	7.83	7.77	7.73	0.10*
		Grass	7.77	7.77	7.84	7.56	0.17*
	46-61	Corn	7.73	7.71	7.76	7.47	n.s.
		Grass	7.79	7.83	7.77	7.77	n.s.
	61-91	Corn	7.56	7.56	7.75	7.58	n.s.
		Grass	7.58	7.85	7.65	7.80	n.s.

a/ Sludge was applied to plots in summer of 1978.
b/ Samples were taken from corn and grass plots in 1981.
*, ** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.
n.s. = not significantly different.

TABLE 16. GRAIN AND STOVER YIELDS FOR CORN, WHEAT, AND RYE AND PLANT POPULATIONS FOR CORN ON SPOIL BANKS WITH AND WITHOUT SLUDGE (CORN WAS PLANTED IN DEAD WHEAT (W) AND RYE (R) MULCH WITH A NO-TILL PLANTER)

Sludge Treatment (mt/ha)	Corn		Wheat	Rye
	(W)	(R)		
	----------Grain Yields (mt/ha)----------			
0	1.07	1.25	nd	0.67
224	3.04	3.68	0.10[a]	0.81
448	4.99	4.45	0.09	0.38
896	6.90	6.83	0.07[a]	0.32
LSD	3.15*	n.s.	-	n.s.
	----------Stover Yields (mt/ha)----------			
0	3.49	3.25	2.36	4.09
224	4.24	5.26	4.64	4.12
448	5.78	5.13	5.15	3.46
896	5.53	4.83	4.45	3.08
LSD	n.s.	n.s.	1.78*	n.s.
	----------Plant Populations (1000/ha)----------			
0	44.5	45.5		
224	41.2	44.5		
448	41.4	44.5		
896	46.7	47.4		

a/ Only two plots.
* Significant at $P \leq 0.05$.
nd = no data due to bird damage.
n.s. = not significant.

TABLE 17. CONCENTRATIONS OF SELECTED ELEMENTS IN CORN LEAF, GRAIN AND STOVER FROM PLOTS WITH AND WITHOUT SLUDGE IN 1981 (CORN WAS PLANTED WITH A NO-TILL PLANTER IN DEAD WHEAT AND RYE)

		Planted in Dead Rye					Planted in Dead Wheat				
		Sludge Application Rates									
		mt/ha									
Element	Tissue	0	224	448	896	LSD	0	224	448	896	LSD
		% (dry weight)									
Mg	leaf	0.37	0.42	0.47	0.50	n.s.	0.49	0.38	0.43	0.61	n.s.
	grain	0.17	0.17	0.16	0.17	n.s.	0.16	0.19	0.18	0.18	n.s.
	stover	0.31	0.26	0.32	0.30	n.s.	0.32	0.28	0.27	0.28	n.s.
Ca	leaf	0.68	0.70	0.82	0.82	n.s.	0.69	0.73	0.70	0.74	n.s.
	grain	0.008	0.006	0.008	0.007	n.s.	0.007	0.008	0.007	0.007	n.s.
	stover	0.32	0.35	0.34	0.30	n.s.	0.31	0.31	0.38	0.29	n.s.
P	leaf	0.29	0.31	0.40	0.39	n.s.	0.32	0.44	0.35	0.36	n.s.
	grain	0.37	0.37	0.37	0.40	n.s.	0.35	0.38	0.38	0.39	n.s.
	stover	0.43	0.37	0.39	0.33	n.s.	0.37	0.52	0.25	0.29	0.16*
N	leaf	1.60	1.40	2.11	2.38	0.27**	1.51	1.56	2.33	2.11	n.s.
	grain	0.84	1.36	1.41	1.16	0.33*	1.01	1.29	1.36	1.39	0.26*
	stover	0.61	0.34	0.63	0.53	0.22**	0.60	0.57	0.67	0.60	n.s.
		mg/kg (dry weight)									
Zn	leaf	28.8	40.4	84.8	98.9	18.2**	23.1	39.9	94.7	106	64**
	grain	31.9	34.3	35.3	42.9	3.3**	30.1	36.1	38.4	41.4	6.2*
	stover	60.4	113	139	142	19.7**	63.8	115	126	141	55**
Fe	leaf	81.8	114	81.8	81.8	n.s.	124	86.7	81.8	91.5	n.s.
	grain	25.3	24.1	24.5	31.7	n.s.	22.0	24.3	26.8	34.5	n.s.
	stover	79.4	76.8	67.0	68.3	n.s.	79.7	77.7	68.8	68.6	n.s.

(continued)

TABLE 17. (continued)

Element	Tissue	Planted in Dead Rye					Planted in Dead Wheat				
		Sludge Application Rates									
		mt/ha									
		0	224	448	896	LSD	0	224	448	896	LSD
		mg/kg (dry weight)									
Mn	leaf	30.1	33.7	49.8	47.9	n.s.	35.8	25.4	40.4	61.7	22.6**
	grain	7.6	4.1	5.6	7.4	2.2**	7.1	4.7	5.8	7.5	1.5**
	stover	30.9	25.3	48.3	56.5	n.s.	34.0	20.0	51.0	59.6	19.0**
Ni	leaf	<0.62	1.54	1.99	1.67	n.s.	<0.62	<0.62	0.84	2.49	1.11**
	grain	1.24	1.20	1.67	2.71	0.66**	1.16	1.24	1.24	2.39	0.94**
	stover	1.52	1.04	1.79	2.03	0.68**	1.63	1.44	1.83	2.11	n.s.
Cr	leaf	<0.125	<0.125	<0.125	<0.125	n.s.	0.323	<0.125	<0.125	<0.125	n.s.
	grain	<0.125	<0.125	<0.125	<0.125	n.s.	<0.125	<0.125	<0.125	<0.125	n.s.
	stover	0.164	<0.125	<0.125	<0.125	n.s.	<0.125	<0.125	<0.125	<0.125	n.s.
Pb	leaf	2.52	2.66	2.80	2.94	n.s.	2.38	1.75	1.50	1.96	n.s.
	grain	1.37	0.99	1.55	3.26	n.s.	1.55	1.46	0.77	2.15	0.76*
	stove	3.10	3.62	3.19	3.19	n.s.	4.22	4.05	4.22	3.53	n.s.
Cd	leaf	0.305	3.76	9.32	7.77	3.73**	0.298	4.81	8.75	6.58	4.06**
	grain	<0.062	0.274	0.524	0.524	0.300**	<0.062	0.327	0.471	0.471	0.298**
	stover	0.286	9.75	16.0	15.8	8.37**	0.241	7.81	17.8	14.4	12.2**
Cu	leaf	5.16	7.11	11.2	14.0	3.88**	6.36	7.79	11.3	15.0	4.42**
	grain	2.23	1.89	2.08	2.39	n.s.	2.14	2.33	2.36	2.65	n.s.
	stover	3.34	5.65	8.06	7.30	2.84**	3.80	6.67	7.86	8.26	2.57*

*, ** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.
n.s. = no significant differences.

Also in agreement with results from previous years, Cd concentrations in corn tissues were not increased by doubling the 448 mt/ha sludge application rate.

The chemical composition of rye and wheat tissues (Table 18), as affected by sludge applications, were similar to those of corn. Concentrations of Ca, Fe, Mn, Cr, and Pb were not affected by sludge applications. Sludge applications caused higher uptakes of Mg and P in all rye tissues, but increases of these elements in wheat tissues were not consistent. Samples of rye and wheat tissues from sludge-treated plots contained higher concentrations of N, Zn, Ni, Cd and Cu than those from control plots. Except for Cd, concentrations of these elements increased with increasingly higher sludge application rates. As was the case for corn tissues, sludge application rates higher than 448 mt/ha did not cause further increased Cd concentrations in small grain tissues.

Concentrations of selected elements in samples of the first and third harvesting of eight species of grasses are shown in Tables 19 and 20. In general, Mg, P, N, Zn, Ni, Cd, and Cu concentrations were enhanced by sludge applications. Sludge applications significantly increased Fe concentrations in three of the eight grass species and insignificant trends for increases of this element in grasses were observed for all species. Concentrations of Mn were significantly increased by sludge applications in two of the grass species. It appears that Mn uptake may be increased only by exceedingly high sludge application rates. Concentrations of Ca, Cr, and Pb in grasses were unaffected by sludge additions.

Grass yields by harvesting time and totals for the year are shown in Table 21 and 22, respectively. By the third year, hardly any of the grasses were present in quantities for harvesting on all replicates, of all sludge treatment levels. By order of listing, tall fescue, Reed canary, orchard, and brome grasses were easy to establish and produced the most favorable yield responses to high-rate sludge applications on mine spoil.

TABLE 18. CONCENTRATIONS OF SELECTED ELEMENTS IN LEAVES, GRAIN AND STOVER OF RYE AND WHEAT FROM PLOTS WITH AND WITHOUT SLUDGE IN 1981

Element	Tissue	Rye					Wheat				
		Sludge Application Rates (mt/ha)									
		0	224	448	896	LSD	0	224	448	896	LSD
		% (dry weight)									
Mg	leaf	0.342	0.438	0.619	0.798	0.169**	0.249	0.306	0.369	0.613	0.210**
	grain	0.170	0.164	0.172	0.192[a]	0.016*	0.210	0.227	0.220	0.232	n.s.
	stover	0.103	0.150	0.172	0.215	0.063**	0.167	0.190	0.197	0.224	n.s.
Ca	leaf	1.05	1.16	1.60	1.45	n.s.	0.408	0.542	0.610	0.726	n.s.
	grain	0.043	0.034	0.037	0.040[a]	n.s.	0.043	0.096	0.062	0.059	0.031*
	stover	0.309	0.356	0.372	0.387	n.s.	0.268	0.326	0.345	0.289	n.s.
P	leaf	0.303	0.341	0.416	0.442	0.098**	0.479	0.570	0.628	0.617	n.s.
	grain	0.505	0.499	0.515	0.590[a]	0.055*	0.605	0.614	0.610	0.633	n.s.
	stover	0.149	0.202	0.247	0.297	0.065**	0.138	0.237	0.249	0.299	0.083**
N	leaf	2.45	2.61	3.89	4.01	1.29*	2.86	2.25	2.71	3.77	n.s.
	grain	2.14	2.56	2.47	2.48[a]	n.s.	2.58	2.53	2.91	2.98	0.341*
	stover	0.491	0.603	0.756	0.867	0.211*	0.582	0.705	0.919	1.01	0.238*

(continued)

TABLE 18. (continued)

Element	Tissue	Rye					Wheat				
		Sludge Application Rates									
		0	224	448	896	LSD	0	224	448	896	LSD
		mt/ha									
		mg/kg (dry weight)									
Zn	leaf	19.5	42.0	70.8	61.3	18.7**	14.9	25.8	39.0	45.9	20.3**
	grain	45.0	63.8	71.6	81.8[a]	21.2**	58.3	69.1	88.7	98.5	23.9**
	stover	21.3	73.8	97.9	125	38.4**	19.0	63.2	76.9	88.7	37.4**
Fe	leaf	118	113	133	114	n.s.	122	120	118	111	n.s.
	grain	41.4	47.0	54.5	39.5[a]	n.s.	nd				
	stover	88.3	85.1	113	89.4	n.s.	65.0	67.8	85.6	74.8	n.s.
Mn	leaf	31.7	18.4	26.3	31.8	8.8*	35.0	21.7	26.0	39.2	n.s.
	grain	23.5	18.3	20.8	24.0[a]	3.0*	35.6	26.7	23.5	25.2	n.s.
	stover	13.5	7.6	10.5	14.7	n.s.	28.7	18.2	18.3	19.9	n.s.
Ni	leaf	<0.62	0.63	1.61	2.05	0.44**	<0.62	<0.62	<0.62	0.95	0.35*
	grain	<0.62	<0.62	1.05	3.32[a]	1.74**	<0.62	0.96	2.22	5.88	2.10**
	stover	<0.62	0.85	1.69	3.28	1.92**	<0.62	0.72	1.38	2.74	1.50**

(continued)

TABLE 18. (continued)

Element	Tissue	Rye					Wheat				
		Sludge Application Rates									
		mt/ha									
		0	224	448	896	LSD	0	224	448	896	LSD
		mg/kg (dry weight)									
Cr	leaf	0.377	0.219	0.748	0.376	n.s.	0.499	0.570	0.998	0.712	n.s.
	grain	0.585	0.549	0.804	0.159[a]	n.s.	0.524	1.57	2.96	5.23	n.s.
	stover	1.46	1.31	1.80	1.04	n.s.	0.925	0.820	0.796	1.01	n.s.
Pb	leaf	3.67	3.95	5.68	5.84	1.50*	2.49	2.70	3.32	3.87	n.s.
	grain	<0.62	<0.62	<0.62	<0.62[a]	n.s.	1.36	2.41	4.14	3.87	n.s.
	stover	2.41	3.15	4.08	2.90	n.s.	2.84	3.27	2.78	2.72	n.s.
Cd	leaf	0.127	0.470	1.04	0.872	0.438**	<0.062	0.703	1.56	1.51	1.18**
	grain	<0.062	0.633	0.740	0.836[a]	0.580**	<0.062	1.70	2.28	2.71	0.804**
	stover	0.209	2.72	3.71	4.31	1.70**	0.196	4.02	3.99	3.78	1.98**
Cu	leaf	9.93	12.9	18.1	18.0	4.63**	6.61	7.50	8.84	9.01	1.51*
	grain	6.56	7.42	8.74	10.0[a]	1.70*	6.08	6.14	6.81	8.72	n.s.
	stover	3.25	4.41	5.99	7.22	1.49**	3.36	4.58	6.42	6.80	1.79**

a/ Only two plots.
*, ** Significant difference at $P \leq 0.05$ and $P \leq 0.01$, respectively.
n.s. = no significant differences.

TABLE 19. CONCENTRATIONS OF SELECTED ELEMENTS IN VARIOUS SPECIES OF GRASSES (FIRST CUT) GROWN ON PLOTS WITH AND WITHOUT SLUDGE

Analyte	Sludge Application Rates, mt/ha				
	0	224	448	896	LSD
	Redtop				
	% (dry weight)				
Mg	0.244	0.299	0.297	0.369	0.058*
Ca	0.357	0.375	0.286	0.232	n.s.
P	0.263	0.346	0.420	0.438	0.115**
N	1.33	1.88	1.86	1.96	n.s.
	mg/kg (dry weight)				
Zn	19.1	45.2	68.4	85.6	23.7**
Fe	50.9	48.5	68.6	65.6	n.s.
Mn	87.3	48.6	47.4	84.7	n.s.
Ni	1.07	2.85	4.15	11.7	4.68**
Cr	0.711	0.427	0.711	0.768	n.s.
Pb	2.23	1.88	1.67	1.88	n.s.
Cd	0.070	0.328	0.746	1.15	0.519**
Cu	4.86	8.48	11.9	13.6	5.57**
	Brome				
	% (dry weight)				
Mg	0.140	0.181	0.214	0.279	0.080**
Ca	0.286	0.250	0.250	0.304	n.s.
P	0.250	0.322	0.344	0.404	0.094**
N	0.981	1.88	1.49	2.43	n.s.
	mg/kg (dry weight)				
Zn	17.1	29.3	40.0	48.1	15.9**
Fe	61.5	69.8	63.9	120	n.s.
Mn	30.5	20.2	24.4	35.9	n.s.
Ni	<0.62	1.10	2.34	4.30	1.34**
Cr	0.917	1.30	0.670	1.81	n.s.
Pb	1.00	0.704	1.47	1.47	n.s.
Cd	0.070	0.825	1.02	1.63	0.692**
Cu	5.46	7.14	7.77	10.2	1.92**

(continued)

TABLE 19. (continued)

Analyte	Sludge Application Rates (mt/ha) 0	224	448	896	LSD
	Orchard				
	%(dry weight)				
Mg	0.183	0.224	0.207	0.277	0.047*
Ca	0.202	0.202	0.183	0.202	n.s.
P	0.293	0.322	0.341	0.379	0.056**
N	1.02	1.56	1.64	1.65	0.41*
	mg/kg (dry weight)				
Zn	20.9	32.1	38.5	49.3	11.8**
Fe	43.1	63.0	51.3	57.1	13.6**
Mn	73.1	38.7	50.2	61.1	19.7*
Ni	1.54	2.21	2.84	8.62	3.40**
Cr	1.74	1.18	1.12	1.12	n.s.
Pb	<0.62	<0.62	<0.62	<0.62	n.s.
Cd	0.180	0.495	1.39	1.73	0.892*
Cu	3.87	6.33	6.62	8.75	3.23**
	Western Wheat				
	% (dry weight)				
Mg	0.113	0.181	0.196	0.235	0.025**
Ca	0.179	0.274	0.256	0.262	n.s.
P	0.281	0.359	0.371	0.372	0.051**
N	1.81	2.16	2.52	2.36	n.s.
	mg/kg (dry weight)				
Zn	19.1	34.6	41.0	43.8	5.1**
Fe	41.4	57.9	62.6	55.6	11.2**
Mn	20.2	19.0	17.8	20.8	n.s.
Ni	<0.62	<0.62	0.925	2.96	1.08**
Cr	0.735	0.904	0.881	0.808	n.s.
Pb	<0.62	1.43	1.08	1.29	0.715**
Cd	<0.062	0.397	0.772	0.720	0.270**
Cu	4.38	7.33	7.50	8.42	0.91**

(continued)

TABLE 19. (continued)

Analyte	Sludge Application Rates (mt/ha) 0	224	448	896	LSD
	Reed Canary (%(dry weight))				
Mg	0.196	0.268	0.299	0.363	0.097**
Ca	0.214	0.208	0.275	0.220	n.s.
P	0.326	0.404	0.480	0.552	0.135**
N	1.61	2.02	2.51	2.41	0.58**
	(mg/kg (dry weight))				
Zn	28.4	61.6	104	121	55.4*
Fe	51.3	60.6	63.0	65.3	n.s.
Mn	40.5	42.3	52.6	89.4	26.5 *
Ni	1.46	3.51	10.7	14.4	9.78**
Cr	0.679	1.18	0.880	0.680	n.s.
Pb	0.642	1.38	1.38	1.31	n.s.
Cd	0.070	0.192	0.596	0.831	n.s.
Cu	6.47	9.32	11.2	12.7	3.66**
	Perennial Rye[a] (% (dry weight))				
Mg	0.243	0.261	0.303	0.329	n.s.
	0.348	0.305	0.354	0.293	n.s.
	0.356	0.409	0.546	0.486	0.108*
	1.31	2.25	2.29	2.62	0.389*
	(mg/kg (dry weight))				
	17.1	39.7	89.8	88.2	50.8**
Fe	81.7	88.8	88.7	120	21.0**
Mn	38.7	30.3	44.1	90.6	34.0**
Ni	1.23	3.62	7.48	15.6	6.72**
Cr	1.09	1.32	1.49	2.78	1.04*
Pb	1.39	1.39	1.53	1.94	0.314*
Cd	<0.062	0.176	0.868	0.680	0.581**
Cu	4.01	5.66	11.3	11.8	6.16**

(continued)

TABLE 19. (continued)

Analyte	Sludge Application Rates (mt/ha) 0	224	448	896	LSD
	Timothy				
	% (dry weight)				
Mg	0.139	0.183	0.192	0.265	0.078*
Ca	0.277	0.244	0.250	0.304	n.s.
P	0.251	0.318	0.355	0.395	0.078*
N	1.48	1.56	2.19	1.84	n.s.
	mg/kg (dry weight)				
Zn	23.4	49.8	64.8	73.6	n.s.
Fe	37.2	42.6	35.5	69.9	n.s.
Mn	36.4	24.8	23.0	34.5	n.s.
Ni	1.35	2.81	4.50	7.78	3.11**
Cr	0.298	0.326	0.411	0.383	n.s.
Pb	2.50	1.30	1.37	1.57	n.s.
Cd	<.062	0.110	0.196	0.753	n.s.
Cu	4.90	8.52	10.1	11.6	3.75*
	Tall Fescue				
	% (dry weight)				
Mg	0.194	0.243	0.265	0.355	0.092*
Ca	0.238	0.257	0.269	0.238	n.s.
P	0.312	0.390	0.409	0.450	n.s.
N	1.36	2.00	2.03	2.31	0.582*
	mg/kg (dry weight)				
Zn	23.2	34.8	48.4	61.5	21.4*
Fe	39.2	52.1	67.3	67.3	n.s.
Mn	21.8	24.2	29.6	50.2	n.s.
Ni	0.940	2.29	5.35	10.4	3.26**
Cr	1.05	1.15	1.20	1.07	n.s.
Pb	<0.62	0.844	<0.62	0.777	n.s.
Cd	0.091	0.386	0.881	1.78	n.s.
Cu	4.57	6.94	7.59	10.2	3.08*

a/ Means for the 896 mt/ha rate based on only two plots.
b/ Means for 0 mt/ha rate based on only two plots.
*, ** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.
n.s. = no significant differences.

TABLE 20. CONCENTRATIONS OF SELECTED ELEMENTS IN VARIOUS SPECIES OF GRASSES (THIRD CUT) GROWN ON PLOTS WITH AND WITHOUT SLUDGE

Analyte	Sludge Application Rates, mt/ha: 0	224	448	896	LSD *
			Redtop		
			%-(dry weight)		
Mg	nd	0.334[a]	0.357[a]	0.498[a]	
Ca		0.594	0.509	0.558	
P		0.379	0.359	0.435	
N		1.82	2.69	3.26	
			mg/kg (dry weight)		
Zn		53.3	90.1	129	
Fe		136	152	322	
Mn		55.8	84.9	82.6	
Ni		4.59	7.35	14.2	
Cr		0.584	0.942	4.14	
Pb		2.86	3.17	4.70	
Cd		1.22	1.95	4.22	
Cu		8.46	11.9	17.6	
			Brome		
			% (dry weight)		
Mg	nd	0.343	0.343	0.407	
Ca		0.581	0.552	0.489	
P		0.411	0.496	0.531	
N		2.36	3.37	4.05	
			mg/kg (dry weight)		
Zn		71.5	97.1	79.8	
Fe		291	132	262	
Mn		32.6	35.1	40.7	
Ni		4.03	3.70	5.33	
Cr		2.57	0.981	0.703	
Pb		3.61	2.80	2.48	
Cd		3.14	4.08	3.49	
Cu		12.9	18.3	20.5	

(continued)

TABLE 20. (continued)

Analyte	Sludge Application Rates (mt/ha) 0	224	448	896	LSD
	Orchard (% dry weight)				
Mg	0.334[a]	0.337[a]	0.323	0.366[a]	0.025*
Ca	0.401	0.325	0.343	0.256	n.s.
P	0.460	0.470	0.400	0.430	n.s.
N	2.16	2.46	2.84	2.70	n.s.
	mg/kg (dry weight)				
Zn	30.6	53.3	63.0	62.8	n.s.
Fe	126	468	263	199	163**
Mn	51.5	49.3	46.7	73.4	n.s.
Ni	2.61	4.84	6.08	9.46	4.26**
Cr	0.682	5.80	3.43	2.58	3.12*
Pb	2.56	5.62	4.74	3.38	n.s.
Cd	0.107	2.21	2.92	2.76	2.07**
Cu	7.92	14.6	16.4	15.6	4.42*
	Western Wheat (% dry weight)				
Mg	0.234[b]	0.277[a]	0.275[a]	0.381[b]	
Ca	0.550	0.484	0.449	0.372	
P	0.304	0.317	0.340	0.435	
N	2.09	2.43	2.50	3.19	
	mg/kg (dry weight)				
Zn	33.7	53.8	72.8	79.8	
Fe	229	152	142	142	
Mn	41.4	21.9	26.0	31.0	
Ni	2.27	2.58	3.09	5.29	
Cr	1.07	0.711	1.68	2.01	
Pb	1.87	1.96	2.33	1.68	
Cd	0.106	2.72	3.74	3.12	
Cu	6.58	8.48	10.1	14.5	

(continued)

TABLE 20. (continued)

Analyte	Sludge Application Rates (mt/ha) 0	224	448	896	LSD
	Reed Canary				
	% (dry weight)				
Mg	0.360[b]	0.358[a]	0.356	0.375	n.s.
Ca	0.484	0.410	0.390	0.325	n.s.
P	0.410	0.546	0.423	0.484	n.s.
N	2.28	2.30	3.16	2.65	n.s.
	mg/kg (dry weight)				
Zn	35.2	99.5	152	206	100*
Fe	441	134	164	214	n.s.
Mn	59.8	50.0	58.7	125	n.s.
Ni	3.40	5.92	10.5	18.2	n.s.
Cr	1.12	0.840	1.90	3.33	n.s.
Pb	3.64	3.54	2.89	4.38	n.s.
Cd	<0.062	0.998	2.08	2.78	1.36*
Cu	8.09	9.28	12.7	14.7	4.42*
	Perennial Rye				
	% (dry weight)				
Mg	0.344[a]	0.398	nd	nd	
Ca	0.612	0.482			
P	0.385	0.572			
N	2.03	2.16			
	mg/kg (dry weight)				
Zn	27.5	52.2			
Fe	135	104			
Mn	44.4	30.6			
Ni	3.27	5.08			
Cr	1.17	0.924			
Pb	1.87	1.53			
Cd	0.070	0.924			
Cu	7.14	9.14			

(continued)

TABLE 20. (continued)

Analyte	Sludge Application Rates (mt/ha) 0	224	448	896	LSD
			Timothy		
			% (dry weight)		
Mg	nd	0.256[a]	0.322	ns	
Ca		0.363	0.565		
P		0.360	0.338		
S		2.44	2.08		
			mg/kg (dry weight)		
Zn		112	101		
Fe		208	166		
Mn		25.1	132		
Ni		6.32	9.23		
Cr		6.89	14.0		
Pb		2.15	7.36		
Cd		1.84	2.98		
Cu		14.1	16.4		
			Tall Fescue		
			% (dry weight)		
Mg	0.449	0.271	0.398	0.498	n.s.
Ca	0.470	0.362	0.398	0.429	n.s.
P	0.483	0.469	0.440	0.452	n.s.
S	1.85	1.61	2.42	2.89	0.91**
			mg/kg (dry weight)		
Zn	22.0	30.6	59.3	88.0	38.9**
Fe	244	120	137	257	n.s.
Mn	33.7	24.7	30.7	60.5	19.6*
Ni	2.96	3.53	5.66	11.7	6.89*
Cr	0.788	1.04	1.80	3.98	n.s.
Pb	2.49	2.61	2.26	5.72	n.s.
Cd	0.509	1.76	3.40	5.95	1.91**
Cu	5.66	7.39	9.50	15.2	5.18**

(continued)

TABLE 20 (continued)

a/ Means for all elements of this grass at this sludge application rate based on only two plots.
b/ Values for all elements of this grass at this sludge application rate based on only one plot.
° Not calculated in all cases due to insufficient data.
*, ** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.
n.s. = no significant differences.
nd = no data for all elements of this grass at this sludge application rate.

TABLE 21. INCREMENTAL GRASS YIELDS FROM PLOTS WITH AND WITHOUT SLUDGE.

Grass	Cutting	Sludge Application Rates, mt/ha: 0	224	448	896
		mt/ha (dry weight)			
Redtop	First	3.24	3.60[a]	6.25[a]	3.82[a]
	Second	0.97	2.00	1.79[a]	1.92[a]
	Third	nd	0.75	0.50	0.71
Brome	First	2.96[b]	5.96	4.62	5.33
	Second	0.66	2.21	2.63	1.46
	Third	nd	0.31	0.19	0.36
Orchard	First	2.90	6.47	7.28	7.06
	Second	0.67[a]	2.56	2.29	2.07
	Third	0.32[a]	0.72	0.51	0.54
Western Wheat	First	5.62[b]	7.87	7.32	8.45
	Second	0.81[a]	2.46[a]	4.20[a]	1.37[b]
	Third	0.18[b]	0.29[b]	0.48[a]	0.09[b]
Reed Canary	First	4.31[b]	5.72[a]	6.31[a]	6.07
	Second	0.81[a]	4.76	4.86	2.31
	Third	0.53[b]	1.17[a]	0.96	0.89
Perennial Rye	First	1.39[a]	3.60[b]	nd	nd
	Second	0.42[a]	1.63[a]	nd	nd
	Third	0.13	0.47[a]	nd	nd
Timothy	First	3.31[a]	5.53	6.36[a]	nd
	Second	0.99[a]	2.75	3.08[a]	nd
	Third	nd	1.09[b]	0.34[a]	nd

(continued)

TABLE 21. (continued)

Grass	Cutting	Sludge Application Rates (mt/ha) 0	224	448	896
		mt/ha (dry weight)			
Tall Fescue	First	3.79	7.41	6.38	6.54
	Second	0.93	1.93	1.83	1.67[a]
	Third	0.37	0.87	0.58	0.68

a/ Mean based on only two plots.
b/ Value based on only one plot.
nd = no data.

TABLE 22. TOTAL GRASS YIELDS FROM PLOTS WITH AND WITHOUT SLUDGE.

	Sludge Application Rates mt/ha				
Grass	0	224	448	896	LSD
	mt/ha (dry weight)				
Redtop	4.21	4.90	6.70	6.90	n.s.
Brome	1.64	8.63	7.83	9.03	5.53**
Orchard	3.56	9.99	10.81	10.65	5.06**
Western Wheat	3.71	9.91	10.66	9.09	n.s.
Reed Canary	3.23	9.37	10.59	12.10	n.s.
Perennial Rye	1.40	3.78	nd	nd	n.s.
Timothy	4.30	8.64	10.40	nd	3.10**
Tall Fescue	5.09	10.48	11.88	10.12	3.50*
LSD	n.s.	n.s.	n.s.	n.s.	

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.
n.s. = no significant differences.
nd = no data.

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